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ARTIFICIALLY SIMULATING THE GEOLOGICAL HISTORY OF CLAY.(U)
JUL 76 J L KNILL, B A CLARK, M H DEFREITAS DA-ERO-124-74-G-0085

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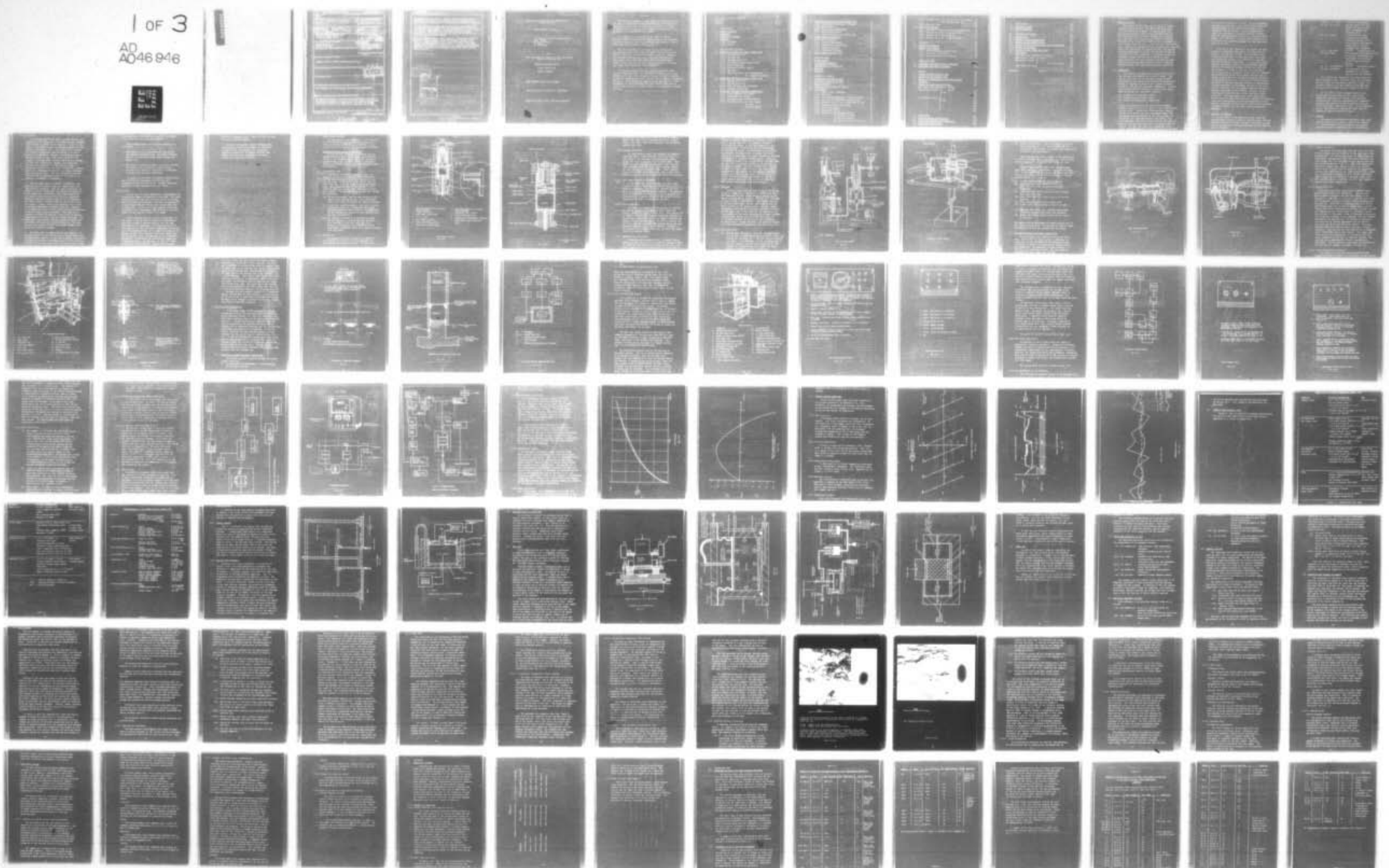

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ARTIFICIALLY SIMULATING THE GEOLOGICAL HISTORY OF CLAY

Final Technical Report

by

J.L. Knill (Principal Investigator)
B.A. Clarke
M.H. de Freitas
D. Jones
M. Rosenbaum

July 1976

With Supplementary Report to cover the period
August to December 1976

EUROPEAN RESEARCH OFFICE

United States Army

London, England.

GRANT NUMBER DA-ERO-124-74-G0085

Imperial College of Science & Technology

Abstract

The research described in this report has been directed to the study of gravitational compaction of clay, by artificially simulating depositional and diagenetic processes in a high pressure cell which can currently impose axial pressures up to 10,000 psi and temperatures up to 100°C.

The purpose of the research is to study the factors associated with the progressive lithifaction of clay sediments, including changes in pore water pressure and chemistry, fabric, mineralogy and geotechnical properties.

The test programme has included the use of kaolinite and montmorillonite clays deposited under both artificial and natural conditions in waters of differing salinity, together with artificial mixtures of clay, a calcite silt and sand. Additionally tests have been conducted at elevated temperatures in two consolidation cells and during one set of tests pore fluid substitution has been attempted.

It has been demonstrated that during progressive gravitational compaction there is a systematic change in pore fluid chemistry and this can be related to changes in fabric relative to both the original pore water salinity and the degree of drainage permitted. Fissuring in the samples tested develops as a direct consequence of rapid unloading but pre-existing flows such as result from microscopic drainage pathways could determine fissure location.

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1. INTRODUCTION

1.1 Purpose of Grant

The purpose of this grant was to enable a research programme, which had been in progress for some years, to be continued and extended. A previous grant from the European Research Office (Contract Number DAJA-37-73-C+4009) had been previously awarded for the period July 1973-June 1974. The research carried out during this period was primarily directed to the development of, and testing associated with, a high pressure consolidation cell. Most of the testing had been concerned with kaolinite clays with pore waters of varying salinity; the applied pressures approached 10,000 psi and all the testing was carried out at room temperature. The present grant was intended to enable the testing to extend to clays associated with other clay minerals (specifically montmorillonite) and to enable temperatures to be applied during testing, thus simulating geothermal conditions.

1.2 Background

The research programme was originally conceived by the Principal Investigator in the early 1960s. The aim, at that time, was to construct a high pressure consolidation cell which could simulate the progressive burial of sedimentary material up to depths of about 10,000 ft. and then its subsequent exhumation. In order that results could be related to natural events three main facilities were considered necessary:

(a) control of "overburden" pressure
(b) control of pore fluid pressure
(c) control of "geothermal" temperature

A grant was obtained from the Natural Environmental Research Council by Dr. P.G. Fookes in 1967, and extended for five years. Research was then directed primarily towards field studies of overconsolidated clays, and development and construction of the high pressure consolidation cell proceeded steadily but slowly. Not until September 1971 was the Consolidation Cell able to compress clay and then only under the crudest forms of control. At that time, with the resignation of Dr. Fookes, the programme was reviewed and the decision taken

to concentrate efforts on the Cell. By the husbanding of financial resources it was possible to proceed with the development of the sophisticated hydraulic and electronic control systems. This development was materially assisted by a grant (DA-ERO-591-73-G0015) from the European Research Office for the period March-August 1973, and then by a second grant referred to in 1.1 above; this research programme has been reported in Knill et al, 1974.

Since early 1973, therefore, the project has been primarily supported by the European Research Office, jointly with Imperial College. At the present time, almost ten years after initial plans were being made for funding the project, it is possible to view the research reasonably objectively. It is now very clear that the mechanical, hydraulic and electronic requirements of the equipment designed in 1967 and 1968 were over-elaborate in terms of the grant then available. In the long-term an invaluable, unique piece of equipment has resulted but it has taken longer, and cost more to design, develop and construct that originally conceived. In retrospect this is not a bad result as the scientific potential of the equipment now available is considerable. The major problems of development can now be said to be solved in that the Cell can produce important scientific results, consistently and reliably. However, further development is possible and, in the long-term, highly desirable. Such development will relate specifically to the control of pore water pressures, method for achieving pore water substitution, in situ instrumentation of the samples undergoing testing, and the control and measurement of radial stresses in the sample during loading and unloading.

1.3 Approach to Problem

At the outset it was appreciated that electrical and mechanical expertise would be required to get the high pressure and other ancillary equipment into working order and to this end the staffing arrangements for the research were as follows:

Professor J.L. Knill:	Principal investigator
Mr. M.H. de Freitas:	Academic member of staff, responsible for co-ordination of academic and technical work.
Mr. B.A. Clarke:	Technician with chief responsibility for all mechanical aspects of the work, and also with general responsibility for all equipment once assembled.
Mr. K. Armstrong:	1973-74)Technicians with
Mr. D.W. Jones:	1974-present)chief responsibility for design, manufacture and maintenance of electrical systems required for the project.
Dr. D.C. Wijeyesekera:	1971-74)Research students
Mr. M.S. Rosenbaum:	1974-present)using the equipment as an integral part of their own research.

Both technicians responsible for electronics have been supported by ERO. Professor Knill, Mr. de Freitas and Mr. Clarke are employed by Imperial College. The research students have been supported by grants from the Natural Environment Research Council of the U.K.

At the time the grant commenced efforts were concentrated on producing reliable, controlled, repeatable compaction of samples. This entailed developing the system for generating axial compaction pressures and maintaining them for periods of up to, and in some cases, exceeding 30 days. It also entailed solving the problems of sealing the fluid used for compaction from the compacting sample.

1.4 Progress

The progress made during the period of this grant basically followed two parallel paths: i.e. progress with the development of the equipment, and progress with the testing and understanding of consolidation.

1.4.1 *Equipment*

The problems associated with attaining reliable and controlled axial compaction in the high pressure equipment centred about a control device referred to later in this report as the pencil piston: an electro-mechanical system that was subjected to wear. This problem was resolved by limited re-design and enabled loading to be satisfactorily accomplished. However, unloading presented a problem because the seals that were used inside the equipment remoulded under pressure and permitted leakage to occur when pressure was reduced. The tests were therefore not repeatable in their latter stages. Considerable project time was spent solving this problem. Seals were redesigned and tested in ancillary equipment; some were purpose made. Once the sealing problems had been overcome the equipment proved to be capable of a reliable, reproducable performance.

The next major area of progress followed, viz. the provision of facilities to heat the sample within the high pressure equipment. Here the major problem was to produce a control system that could bring the sample to a set temperature and maintain that temperature whilst also permitting the controls for the axial compaction system to cope with thermal expansion of the equipment, the fluid used for compaction and the pore fluid within the sample. Control systems and components were tested on ancillary equipment (standard laboratory oedometers and a Rowe Cell) prior to their selection and installation within the high pressure equipment. Only then was it possible to assess the response of the seals to elevated temperatures; once again sealing problems developed. Our experience from previous sealing problems permitted this difficulty to be overcome relatively quickly. The seals have now been proven to 80^{o}C, the present thermal limit of our soil testing programme.

The third area of progress could then commence, viz. the substitution of pore fluid within a sample under test. Here, as before, complete systems were designed, constructed and tested on ancillary equipment prior to their selection. A system has now been chosen and is currently being tested,

in conjunction with a Rowe Cell, prior to its install-ation within the high pressure equipment.

This project leaves two areas of progress to be fulfilled:

1. The provision of a system that will control the pore pressure gradient within the sample and hence the rate at which pore fluid passes through the sample, and

2. The controls required to enable the radial stresses developed within a sample to be measured and balanced by an hydraulic fluid that is independent from that used for axial compaction.

It should be noted that the progress reported here has relied on the development of much ancillary equipment and the modification of standard laboratory apparatus, notably oedometers and shear boxes.

1.4.8 *Testing*

At the time the grant commenced Mr. Wijeyesekera was studying the compaction behaviour of kaolinite. The broad objectives of this work were related to rates of loading. Later the study was broadened to include a consideration of pore fluid chemistry and how this varied with rates of compaction. A total of 16 high pressure tests were completed by Mr. Wijeyesekera and described in the 1974 report for the contract (DAJA-37-73-C-4009).

As most natural deposits of clay are mixtures of pure clays it was decided to follow Mr. Wijeyesekera's work with a study of montmorillonite: this has been undertaken by Mr. Rosenbaum. The broad objectives of this work are to study the effect temperature and initial pore fluid chemistry have on the compaction process, the changes in pore fluid chemistry that occur during com-paction and the effect of compaction on the mechanical properties, in particular the geotechnical properties, on montmorillonite. [illegible] high pressure tests have been completed to the present date (August 1976) together

with 15 low pressure tests. Details of all the tests are given in later chapters.

Both Mr. Wijeyesekera and Mr. Rosenbaum have written papers describing elements of their work. In addition Mr. Wijeyesekera has successfully submitted a thesis for the degree of Ph.D. from London University; Mr. Rosenbaum is currently writing the thesis for his Ph.D.

2. HIGH PRESSURE EQUIPMENT

The high pressure, high temperature work associated with this project has been conducted in a purpose built vessel, the mechanical and electrical systems of which are described here, together with its overall performance.

2.1 Mechanical systems available in 1973

By 1973 the basic components of the high pressure apparatus had been made and assembled, and preliminary testing of the equipment was in hand. Soil testing was also conducted in the equipment, partly to gain experimental results and partly to evaluate the equipment under test conditions.

2.1.1 *Consolidation cell*

This is the main piece of equipment: Fig. 2.1a. Basically it consists of a pressure vessel assembled from two large machined forgings each containing removable end plugs. The forgings, in the form of upper and lower tubes (Fig. 2.1a) are joined by a threaded toggle ring. These components have all been designed with a factor of safety of 2.0 over their yield point at 200°C and 10,000 psi. The principal factors of the basic design are as follows.

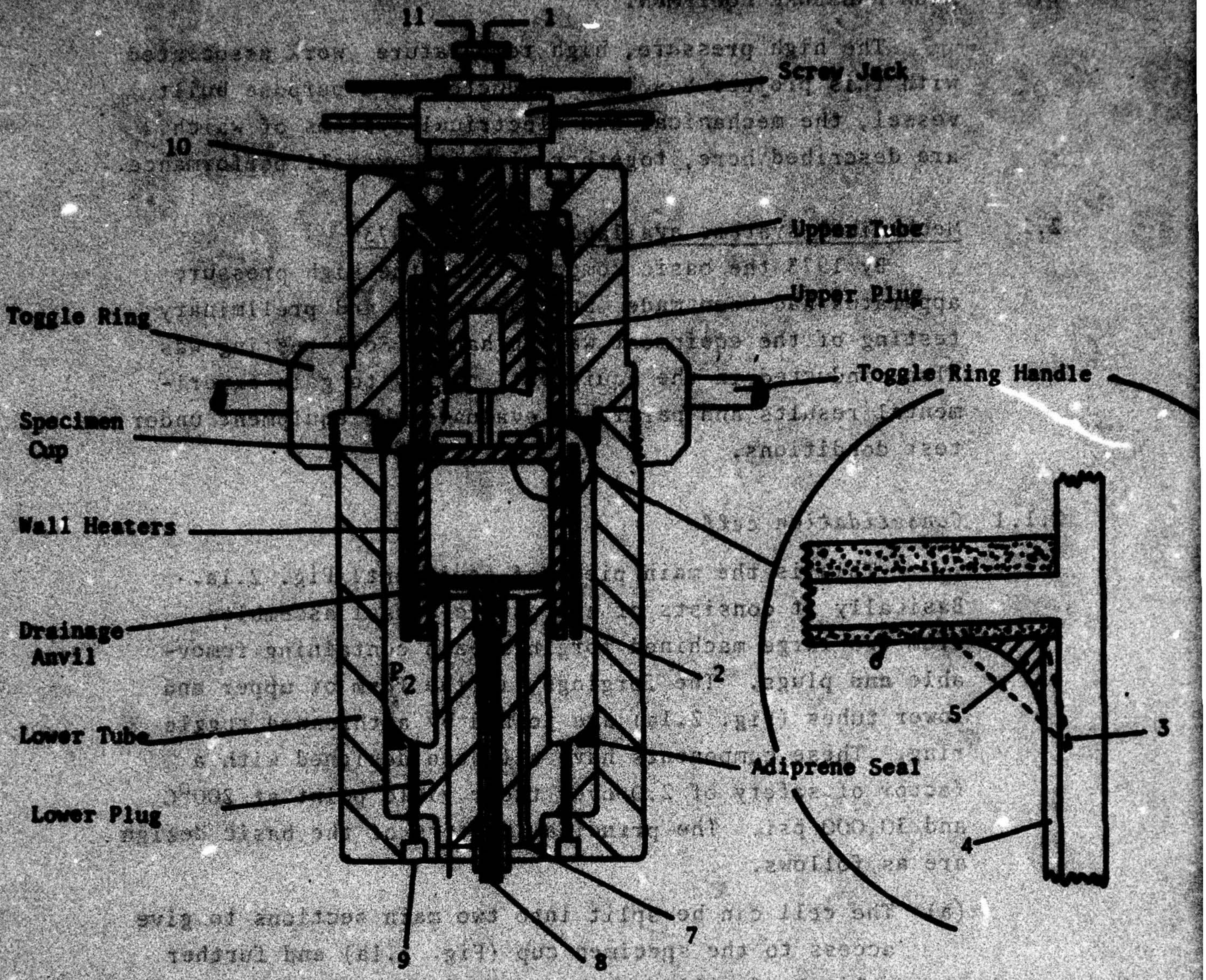
(a) The cell can be split into two main sections to give access to the specimen cup (Fig. 2.1a) and further split to facilitate the removal of compacted specimens.

(b) A precision, pressure-balanced, screw jack is present in the upper plug (Fig. 2.1a) for housing the displacement transducer used to measure axial compaction and for adjusting the position of the transducer when the cell is pressurised.

(c) The specimen is mounted in an inverted cup which, during compaction, is pressed down over an anvil, this being part of the lower plug (Fig. 2.1b). Movement of the specimen cup is monitored by the displacement transducer, housed in the pressure-balanced screw jack above.

2.1.2 *Specimen cup*

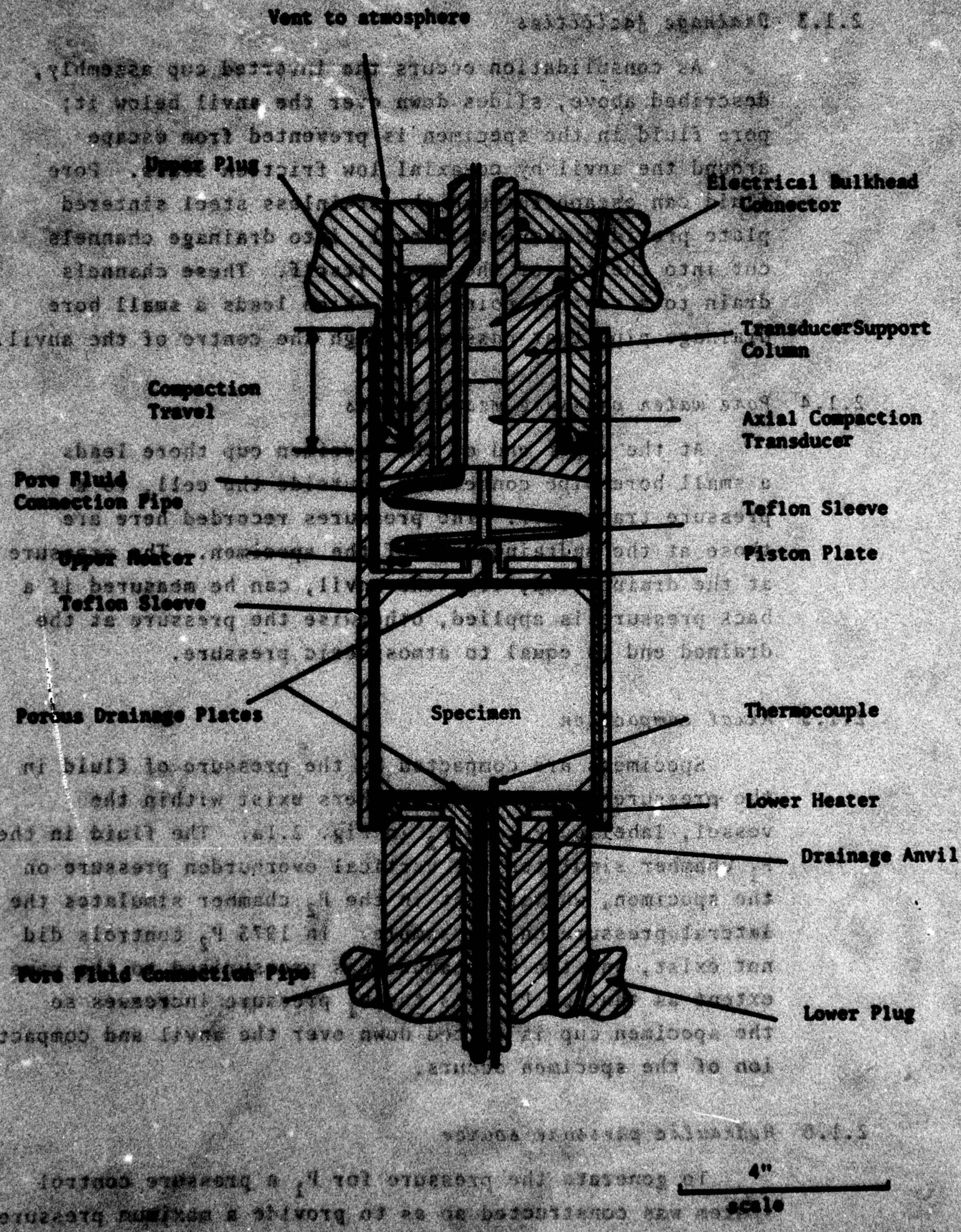
The specimen cup itself is made of low expansion steel (Nilo 36) to assist the accurate measurement of consolidation when the cup is heated. The inner walls



1. **Pore Fluid Connection to undrained end of specimen**
2. **Thermal Insulation**
3. **Wiper Blade relaxed shape**
4. **P.T.F.E. Liner**
5. **Wiper Blade in position**
6. **Porous Steel Drainage Plate**
7. **Connections to Lower Heaters**
8. **Pore Fluid Connection to drained end of specimen**
9. **Temperature Probe (Lower)**
10. **Pressure Balanced Piston**
11. **Connections to Displacement Transducer Upper Heater, Upper Temperature Probe**

Cell General Assembly

Fig. 2.1a



Vent to atmosphere
Upper Plug
Electrical Bulkhead Connector
Transducer Support Column
Compaction Travel
Axial Compaction Transducer
Pore Fluid Connection Pipe
Teflon Sleeve
Upper Heater
Piston Plate
Teflon Sleeve
Porous Drainage Plates
Specimen
Thermocouple
Lower Heater
Drainage Anvil
Pore Fluid Connection Pipe
Lower Plug
4"
scale

Fig. 2.1(b)

drag on the sides of the specimen and on the co-axial seals. The liners would also function as an insulation against heat loss.

2.1.3 *Drainage facilities*

As consolidation occurs the inverted cup assembly, described above, slides down over the anvil below it; pore fluid in the specimen is prevented from escape around the anvil by co-axial low friction seals. Pore fluid can escape through the stainless steel sintered plate provided above the anvil, into drainage channels cut into the top of the anvil itself. These channels drain to a central point from which leads a small bore drainage pipe that passes through the centre of the anvil.

2.1.4 *Pore water pressure measurements*

At the upper end of the specimen cup there leads a small bore pipe connecting, outside the cell, to a pressure transducer. The pressures recorded here are those at the undrained end of the specimen. The pressure at the drained end, i.e. the anvil, can be measured if a back pressure is applied, otherwise the pressure at the drained end is equal to atmospheric pressure.

2.1.5 *Axial compaction*

Specimens are compacted by the pressure of fluid in the pressure vessel. Two chambers exist within the vessel, labelled P_1 and P_2 in Fig. 2.1a. The fluid in the P_1 chamber simulates the vertical overburden pressure on the specimen, whilst that in the P_2 chamber simulates the lateral pressure on the sample. In 1973 P_2 controls did not exist, and the P_2 chamber was pressurised to the same extent as that of P_1. As the P_1 pressure increases so the specimen cup is forced down over the anvil and compaction of the specimen occurs.

2.1.6 *Hydraulic pressure source*

To generate the pressure for P_1 a pressure control system was constructed so as to provide a maximum pressure of 10,000 psi that could be held constant at a set value with a stability of $\pm$ 1%: this system is illustrated in

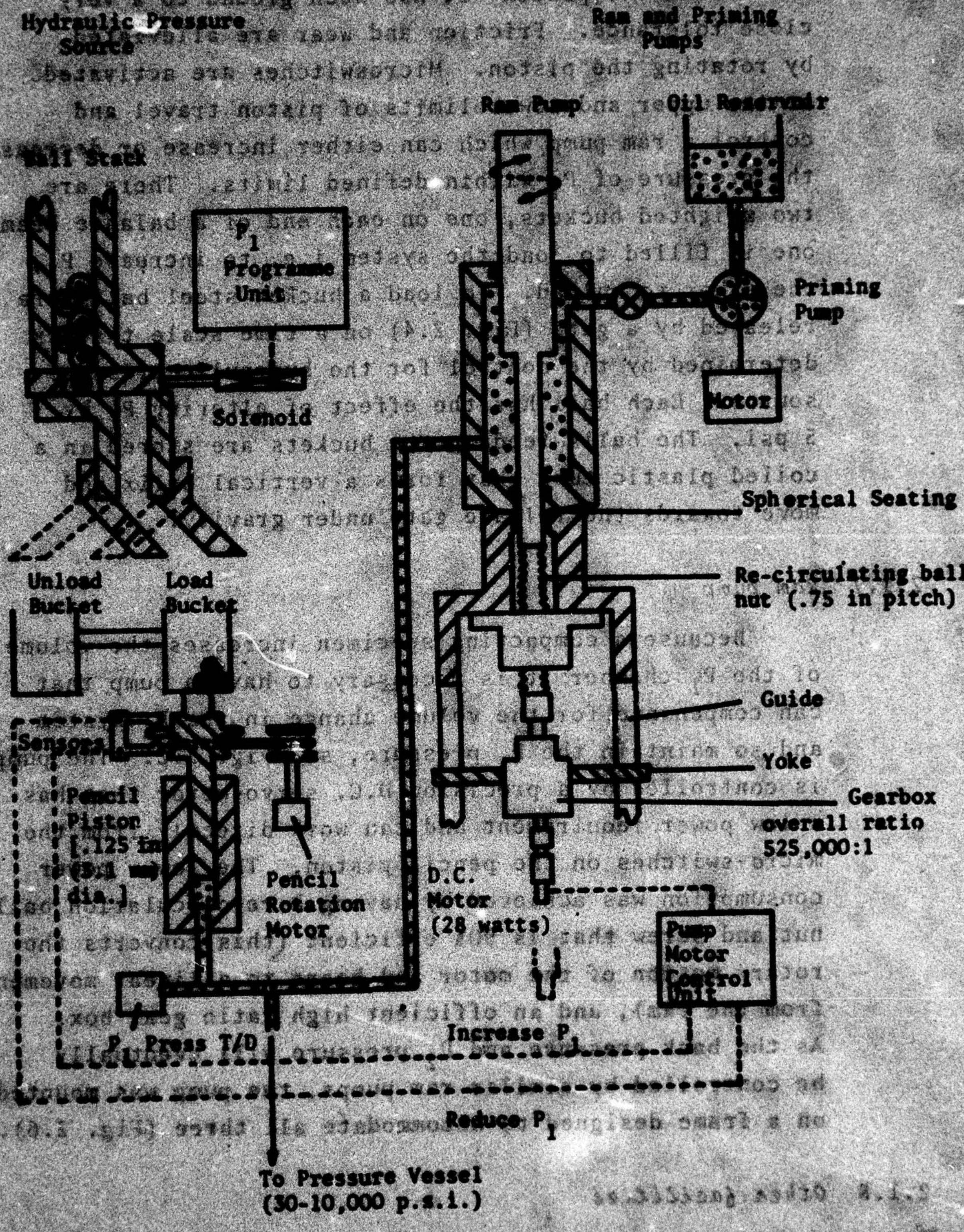
between a weighted bucket and the hydraulic fluid of the P_1 system, Fig. 2.3. To eliminate leakage of oil around the piston, it has been ground to a very close tolerance. Friction and wear are alleviated by rotating the piston. Microswitches are activated at the upper and lower limits of piston travel and control a ram pump which can either increase or decrease the pressure of P_1 within defined limits. There are two weighted buckets, one on each end of a balance beam: one is filled to load the system i.e. to increase P_1, the other to unload. To load a bucket steel balls are released by a gate (Fig. 2.4) on a time scale that is determined by the control for the hydraulic pressure source. Each ball has the effect of altering P_1 by 5 psi. The balls feeding the buckets are stored in a coiled plastic tube that forms a vertical helix and move towards the release gate under gravity.

2.1.7 *Ram pump*

Because a compacting specimen increases the volume of the P_1 chamber it is necessary to have a pump that can compensate for the volume change in the P_1 system and so maintain the P_1 pressure, see Fig. 2.2. The pump is controlled by a precision D.C. servo-motor that has a low power requirement and can work directly from the micro-switches on the pencil piston. The low power consumption was achieved by having a re-circulation ball nut and screw that is 90% efficient (this converts the rotary motion of the motor and gears to a linear movement from the ram), and an efficient high ratio gear box. As the back pressure and P_2 pressure will eventually be controlled by similar ram pumps, the pump was mounted on a frame designed to accommodate all three (Fig. 2.6).

2.1.8 *Other facilities*

(a) Priming pump. Because the hydraulic pressure source (2.1.6) has a minimum operating pressure of 70 psi, and because the ram pump (2.1.7) can only deliver fluid at low rates, it was necessary to have a priming pump so that the hydraulic system may be purged of air and brought to a pressure that will enable the pencil piston to operate; see Figs. 2.2 and 2.5.



T/D - Transducer

Axial Pressure System

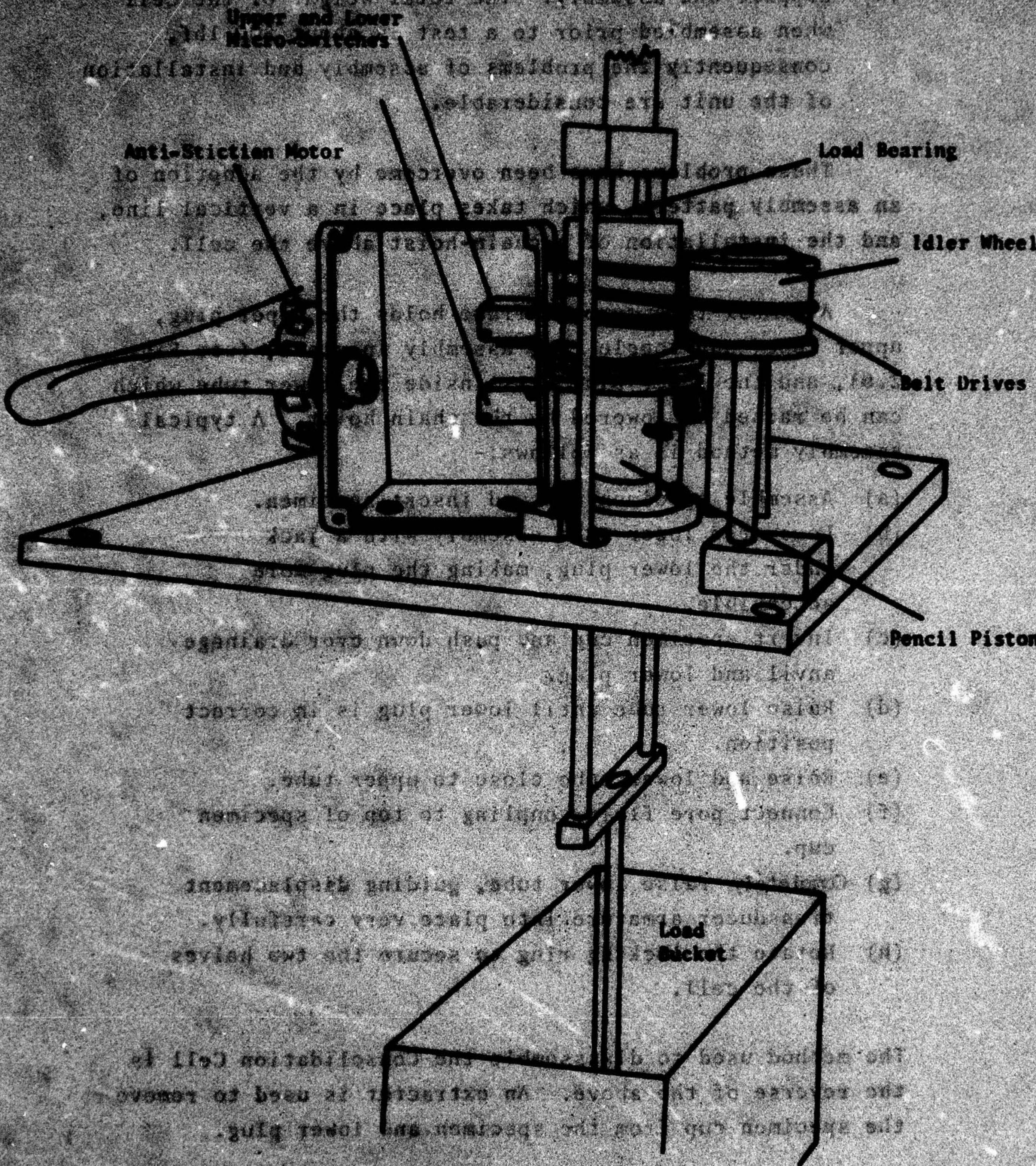
Fig. 2.2

(b) Support and assembly. The total weight of the cell when assembled prior to a test [illegible] lbf, consequently the problems of assembly and installation of the unit are considerable.

These problems have been overcome by the adoption of an assembly pattern which takes place in a vertical line, and the installation of a chain-hoist above the cell.

A [illegible] holds the upper plugs, upper [illegible] cell assembly [illegible], and the [illegible] inside the upper tube which can be raised and lowered by the chain hoist. A typical assembly pattern is as follows:-

(a) Assemble [illegible] and insert specimen.
(b) [illegible] assembly with a jack under the lower plug, making the [illegible] possible.
(c) Insert specimen cup and push down over drainage anvil and lower plug.
(d) Raise lower case until lower plug is in correct position.
(e) Raise and lower tube close to upper tube.
(f) Connect pore fluid coupling to top of specimen cup.
(g) Carefully raise upper tube, guiding displacement transducer armature into place very carefully.
(h) Rotate [illegible] ring to secure the two halves of the cell.



The method used to dismantle the Consolidation Cell is the reverse of the above. An extractor is used to remove the specimen cup from the specimen and lower plug.

2.2 Mechanical systems available: August 1976

The development work undertaken during the three years 1973 to 1976 was mainly aimed at improving the reliability of the equipment and providing additional facilities to enhance the simulation of natural burial and exhumation. The mechanical systems available in 1973 are still available in 1976. One new system of importance has been added, viz. heating.

Hydraulic Pressure Source

Fig. 2.3

(b) Support and assembly. The total weight of the Cell when assembled prior to a test is about 500 lbf, consequently the problems of assembly and installation of the unit are considerable.

These problems have been overcome by the adoption of an assembly pattern, which takes place in a vertical line, and the installation of a chain-hoist above the cell.

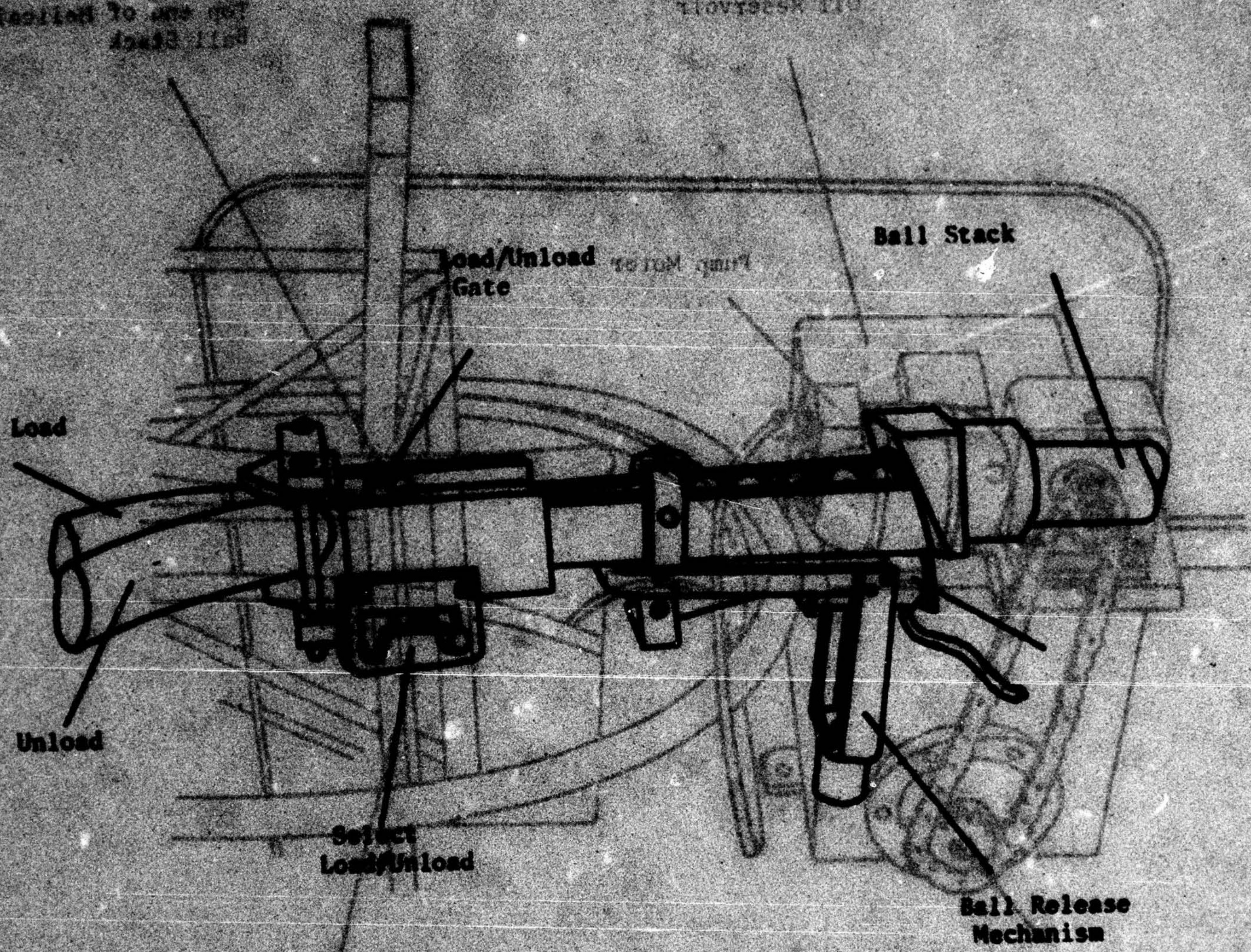
A gimbal-type support frame holds the upper plug, upper tube, and toggle ring assembly in place, (see Fig. 2.6), and the lower plug sits inside the lower tube which can be raised or lowered by the chain hoist. A typical assembly method is as follows:-

(a) Assemble specimen cup and insert specimen.
(b) Lower the lower tube assembly with a jack under the lower plug, making the plug more accessible.
(c) Invert specimen cup and push down over drainage anvil and lower plug.
(d) Raise lower tube until lower plug is in correct position.
(e) Raise and lower tube close to upper tube.
(f) Connect pore fluid coupling to top of specimen cup.
(g) Completely raise lower tube, guiding displacement transducer armature into place very carefully.
(h) Rotate the locking ring to secure the two halves of the cell.

The method used to disassemble the Consolidation Cell is the reverse of the above. An extractor is used to remove the specimen cup from the specimen and lower plug.

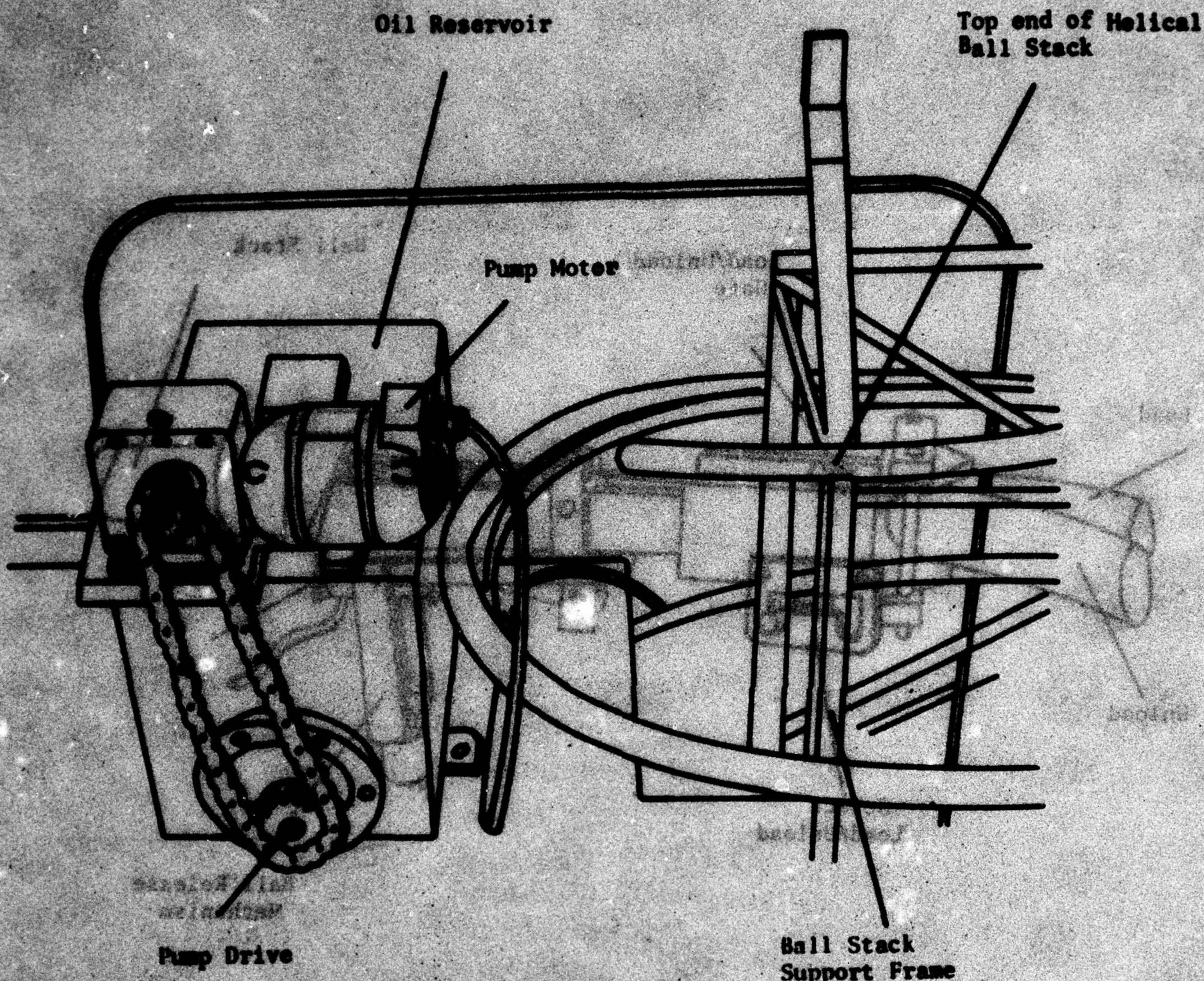
2.2 Mechanical systems available; August 1976

The development work undertaken during the three years 1973 to 1976 was mainly aimed at improving the reliability of the equipment and providing additional facilities to enhance the simulation of natural burial and exhumation. The mechanical systems available in 1973 are still available in 1976. One new system of importance has been added, viz. heating.



Ball Release Mechanism

Fig. 2.4



Priming Pump

Fig. 2.5

2.2.1 *Heating facilities*

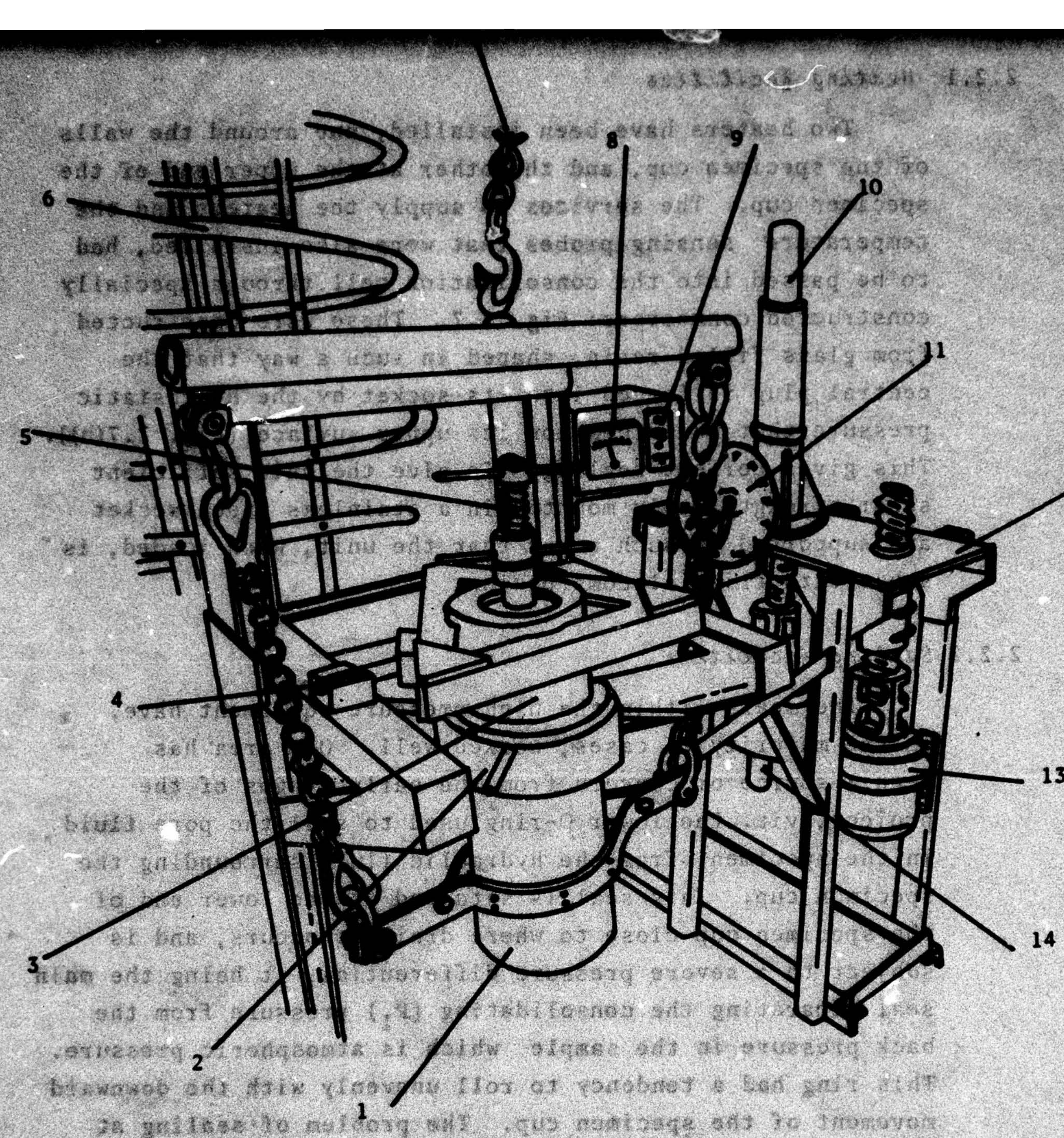
Two heaters have been installed, one around the walls of the specimen cup, and the other at the upper end of the specimen cup. The services to supply the heaters and the temperature sensing probes that were also installed, had to be passed into the consolidation cell through specially constructed connectors: Fig. 2.7. These were constructed from glass filled resin, shaped in such a way that the central plug is forced into its socket by the hydrostatic pressure that would bear on its upper surface (Fig. 2.7(b)). This gives perfect sealing. To give the unit sufficient shear strength it is mounted in a stainless steel socket and supported in such a way that the unit, when loaded, is subject to triaxial compression.

2.2.2 *Sealing facilities*

The seals within the high pressure equipment have, in the majority of cases, worked well. One area has been a source of concern from the early stages of the project, viz. the lower O-ring used to seal the pore fluid in the specimen from the hydraulic fluid surrounding the specimen cup. This seal is situated at the lower end of the specimen cup close to where drainage occurs, and is subject to a severe pressure differential, it being the main seal separating the consolidating (P_1) pressure from the back pressure in the sample which is atmospheric pressure. This ring had a tendency to roll unevenly with the downward movement of the specimen cup. The problem of sealing at the lower end was further aggravated when the heaters were used, as the O-ring would also remould. This seal therefore had to be replaced after each test; a costly procedure. This seal has now been replaced by an energised viton rubber PTFE seal of flat section. This means that the seal sits in a housing that is of similar size and shape; remoulding of the seal is therefore reduced. One seal now lasts approximately 10 tests, depending on conditions. The new materials used reduce the friction of the seal and its tendency to remould: see Fig. 2.8.

2.2.3 *Anti-contamination facilities*

The chemistry of the pore fluids expelled during compaction became a subject of considerable interest during



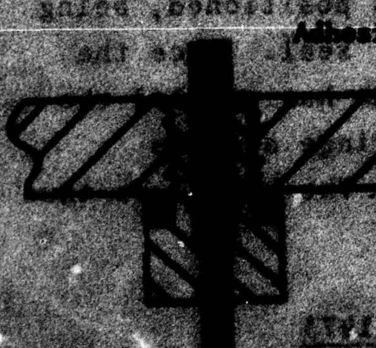
Cell and Ram Pump Assembly

1. Cell Lower Tube
2. Toggle Ring
3. Cell Upper Tube
4. Gimbal-type Supports
5. Screw Jack
6. Part of Ball Stack
7. Part of Chain Hoist
8. Axial Displacement Meter
9. Priming Pump Remote Control
10. P_1 Ram Pump
11. P_1 Pressure Gauge
12. Frame for 3 Pumps
13. Gearbox
14. D.C. Servo Motor on P_1 Pump

Fig. 2.6

2.7(a): An early seal. Pin head prevented extrusion of pin and PTFE made an effective seal with the cone preventing extrusion. Although successful this seal was not used as pins could not be placed in close proximity.

2.7(b): 8-way connector (commercially available) rated to 20,000 psi and 100°C.



2.7(c): Multi-cone aluminium oxide ceramic with a base sealed by an anaerobic adhesive. A suitable adhesive has not yet been found.

Electrical Connectors

Fig. 2.7

the three years, and every effort was made to reduce contamination of the pore fluids involved. The areas most vulnerable to contaminating leaks were at the upper and lower ends of the specimen cup, and at the discharge point of the drainage tube leading from the specimen. The upper end of the specimen cup is now sheathed in a rubber membrane. This ensures that leakage due to the expansion of materials at supposedly sealed joints did not permit the hydraulic fluid to penetrate the sample. This system works well. The lower end of the specimen cup is now protected by the viton rubber PTFE seal described in the previous section. The discharge point of the drainage tube now connects directly to a disposable medical syringe made of inert plastic. A pore pressure as low as 1.5 psi is sufficient to activate the syringe. Syringes can be changed in a matter of seconds. Samples are stored in them until analysed.

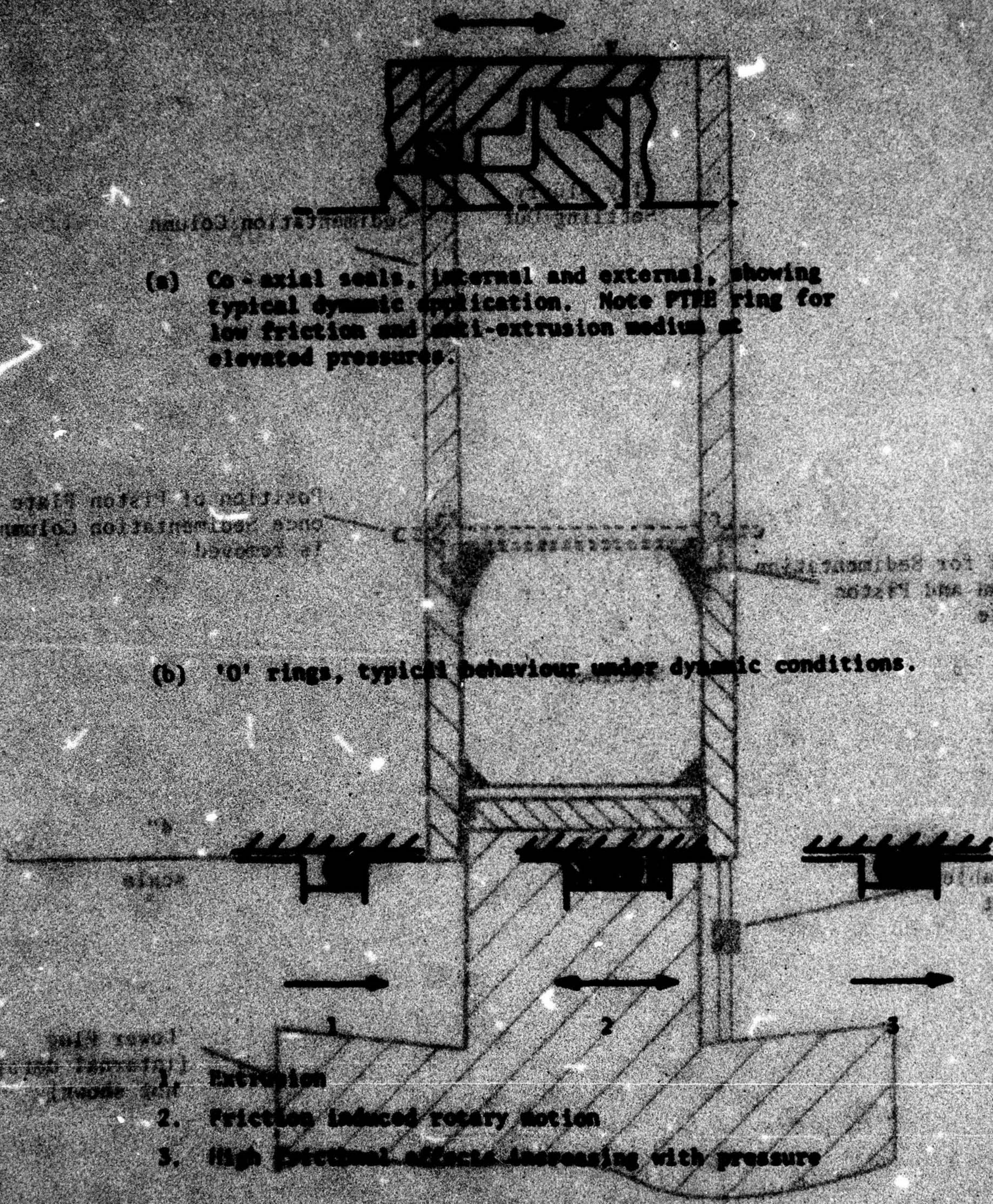
2.2.4 *Specimen preparation*

At the early stages of the programme of testing considerable concern was expressed about the condition of the specimens tested, i.e. they were remoulded, and hence had a structure that was not typical of sedimented deposits. A column extension was therefore made that could be attached to the specimen cup which enabled specimens to be sedimented directly into the specimen cup: undisturbed specimens are thus obtained. To use the column, which has the same internal diameter as the specimen cup, the piston plate is removed (Figs. 2.1b and 2.9) and the sedimentation column positioned, being held to the specimen cup by a special seal. Once the sediment within the cup and the column has settled the excess fluid is drawn off with a syringe and the drainage and piston plates replaced. The sample is thus encased within the specimen cup.

2.3 Electrical systems available; August 1973

The systems available could be divided into three groups: those for,

(a) the generation and maintenance of consolidating, or axial pressure (P_z)



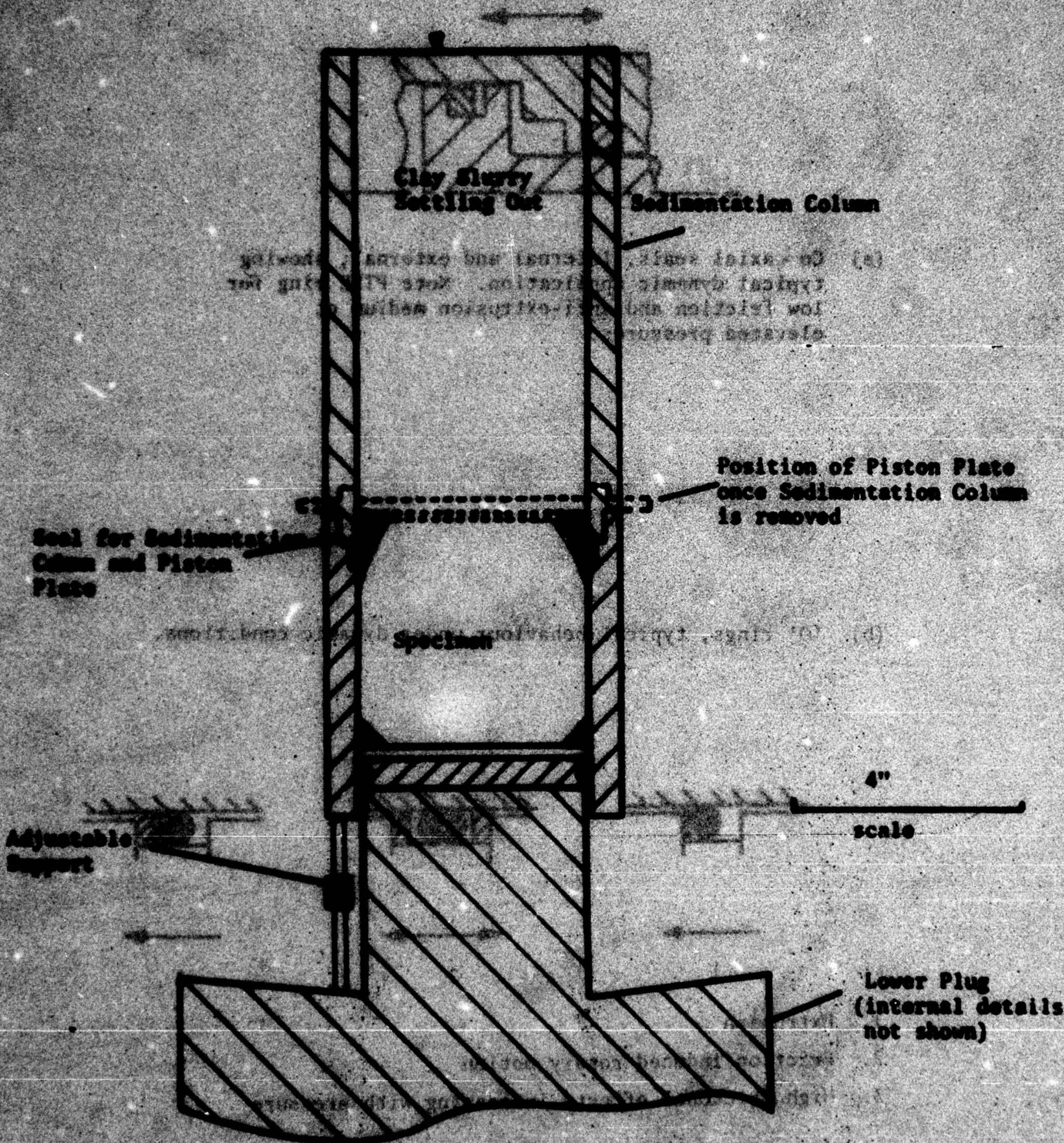
(a) Co - axial seals, internal and external, showing typical dynamic application. Note PTFE ring for low friction and anti-extrusion medium at elevated pressures.

(b) 'O' rings, typical behaviour under dynamic conditions.

1. Extrusion
2. Friction induced rotary motion
3. High frictional effects increasing with pressure

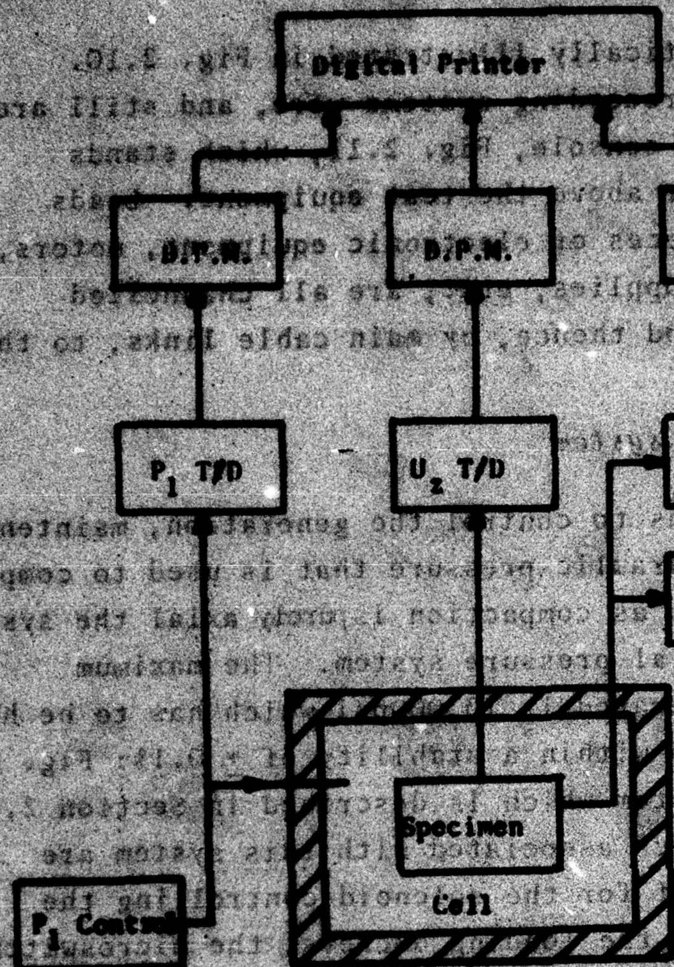
A Comparison of Sealing Conditions

Fig. 2.8



Sedimentation Column and Piston Plate

Fig. 2.9



T/D = Transducer

D.P.M. = Digital Panel Meter

ΔH = Change in specimen length

P_1 = Axial Pressure

U_z = Pressure at undrained end of specimen

Electrical Systems installed July 1973

Fig. 2.10

(b) the measurement and control of pore water pressure (u_z)

(c) the measurement of consolidation (Δh)

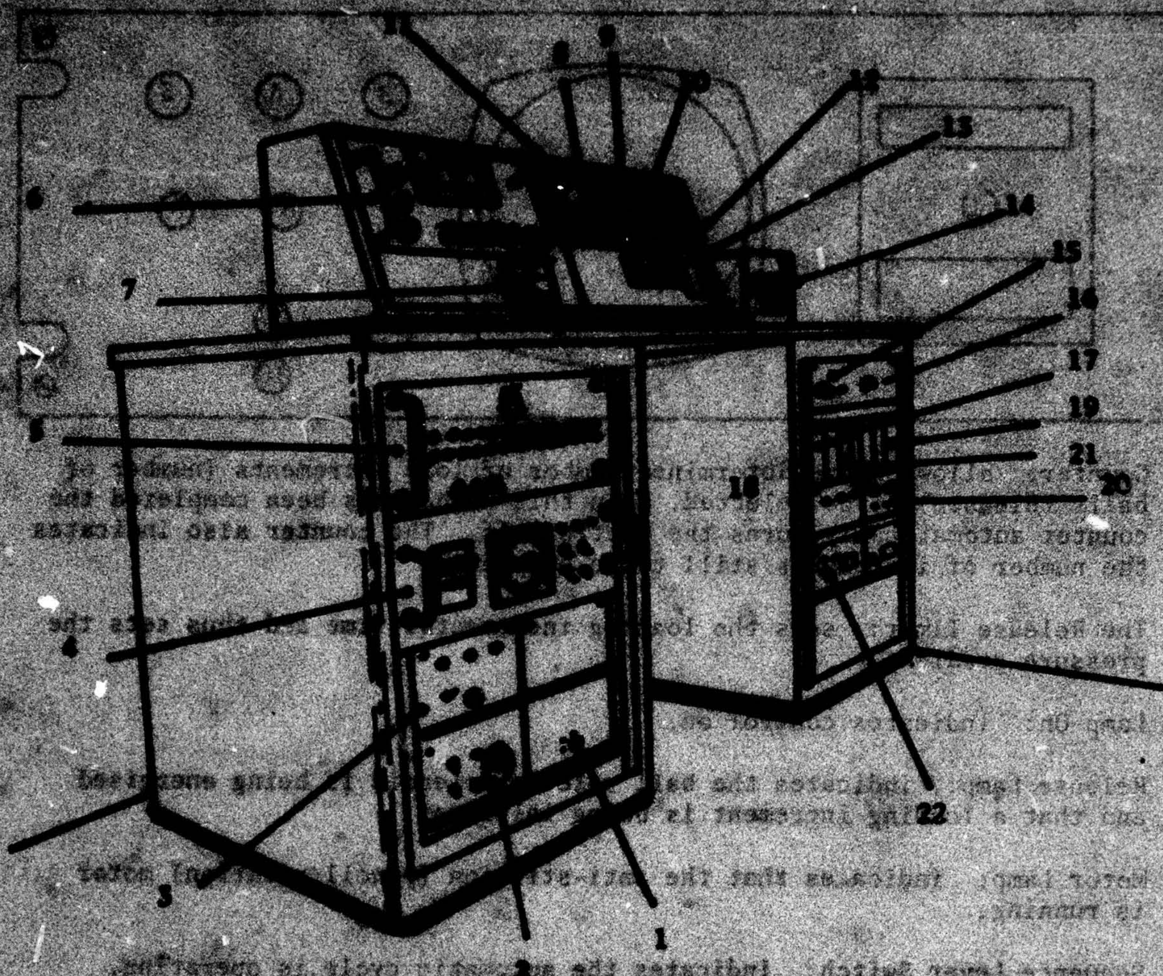
These are diagrammatically illustrated in Fig. 2.10. All monitoring and recording systems were, and still are, housed in a control console, Fig. 2.11, which stands on a mezzanine floor above the test equipment. Leads from the various pieces of electronic equipment, motors, transducers power supplies, etc., are all channelled to terminal boxes and thence, by main cable links, to the control console.

2.3.1 *Axial pressure (P_1) system*

This system has to control the generation, maintenance and decay of an hydraulic pressure that is used to compact the test specimens: as compaction is purely axial the system is known as the axial pressure system. The maximum pressure to be generated is 10,000psi which has to be held, at any pressure, to within a stability of $\pm$ 0.1%: Fig. 2.2 illustrates the system which is described in Section 2.1. The basic electronics associated with this system are the programming unit for the solenoid controlling the release of balls to the loading buckets, the microswitches that sense the resulting movement of the pencil pison, and the motor that drives the ram pump.

The ball time release mechanism that controls the solenoid automatically releases balls from the ball stack at programmed intervals of time, ceasing at a specified count equivalent to the maximum load required. This automatic system can be overridden by a manual control. Fig. 2.12 illustrates the control panel.

The micro-switch sensors monitor the position of the pencil piston. This is a floating piston supported by an hydraulic pressure, from the ram pump, that balances the load applied to it from the loading buckets. This balance is sensed by the micro-switches. When the pencil sinks below the balance point the lower sensor activates the ram pump motor and the hydraulic pressure in the P_1 line is increased. This continues until the pencil returns to its balance point, at which level the



Control Console

1. Alarm Unit
2. Priming Pump Control Unit
3. Ram Pump Control Unit
4. Hydraulic Pressure Source Control
5. Power Supply Unit
6. Displacement Transducer Bridge
7. Displacement Meter ± 0.5 inches
8. Bridge Error Voltage DPM*
9. Main Temperature DPM
10. P_1' Pressure DPM
11. Clock Time Display
12. Printer Control Panel
13. u_s Pressure DPM
14. Digital Printer
15. P_1 Signal Conditioner
16. u_2 Signal Conditioner
17. Temperature Measurement Unit
18. Temperature Display Selector Unit
19. Displacement Transducer Bridge Buffer Amp
20. Heater (lower) Control Unit
21. Temperature Set
22. Voltage Reference Unit

* DPM - Digital Panel Meter

Fig. 2.11

1. Counter: allows a pre-determined number of load increments (number of balls released) to be selected. When this number has been completed the counter automatically turns the control off. The counter also indicates the number of increments still to be completed.

2. The Release Timer: sets the loading incremental time and thus sets the pressure gradient.

3. Lamp On: indicates control on.

4. Release Lamp: indicates the ball release solenoid is being energised and that a loading increment is being initiated.

5. Motor Lamp: indicates that the anti-stiction (pencil rotation) motor is running.

6. Sequence Lever Switch: indicates the automatic cycle is operating.

7. Turns on anti-stiction (pencil rotation) motor.

8. Release Pushbutton: permits loading to be carried out manually each alternation giving one load increment.

9. Switch for automatic-manual mode of operation.

10. Main fuse for supply.

Ball Time Release Mechanism

Fig. 2.12

1. Lamps: show control is in operation
2. Lamps: show control is in operation
3. Lamps: show control is in operation
4. Switch: ON-OFF for unit
5. Switch: manual increase
6. Switch: manual decrease
7. Switch: select for automatic or manual
8. Fuse

Ram Pump Control Unit

Fig. 2.13

upper sensor terminates the action. Because this system is liable to leakage and mechanical wear facilities have been provided that enable the ram pump motor to be operated using the manual controls illustrated in Fig. 2.13. The micro-switches continue to operate when the system is under manual control and will delay any change in pressure that increases imbalance.

The ram pump motor is controlled so as to increase or decrease the load provided by the ram pump on the hydraulic fluid for the P_1 system. Maximum travel is protected by limit switches which automatically stop further movement when the limit of ram pump travel has been reached.

In addition to these basic items there is also a priming pump which has a variable speed control that can be pre-set at any designed rate. This primes the ram pump to 70 psi, and purges the system of air. Once at 70 psi the pressure pencil piston system can operate efficiently. A pressure switch prevents excessive pressures being developed in the system whilst the priming pump is in operation. The pump is controlled by a simple ON-OFF unit with a remote control terminal situated near the test equipment so that the pump can be controlled by the test operator.

The entire P_1 system is illustrated in Fig. 2.14.

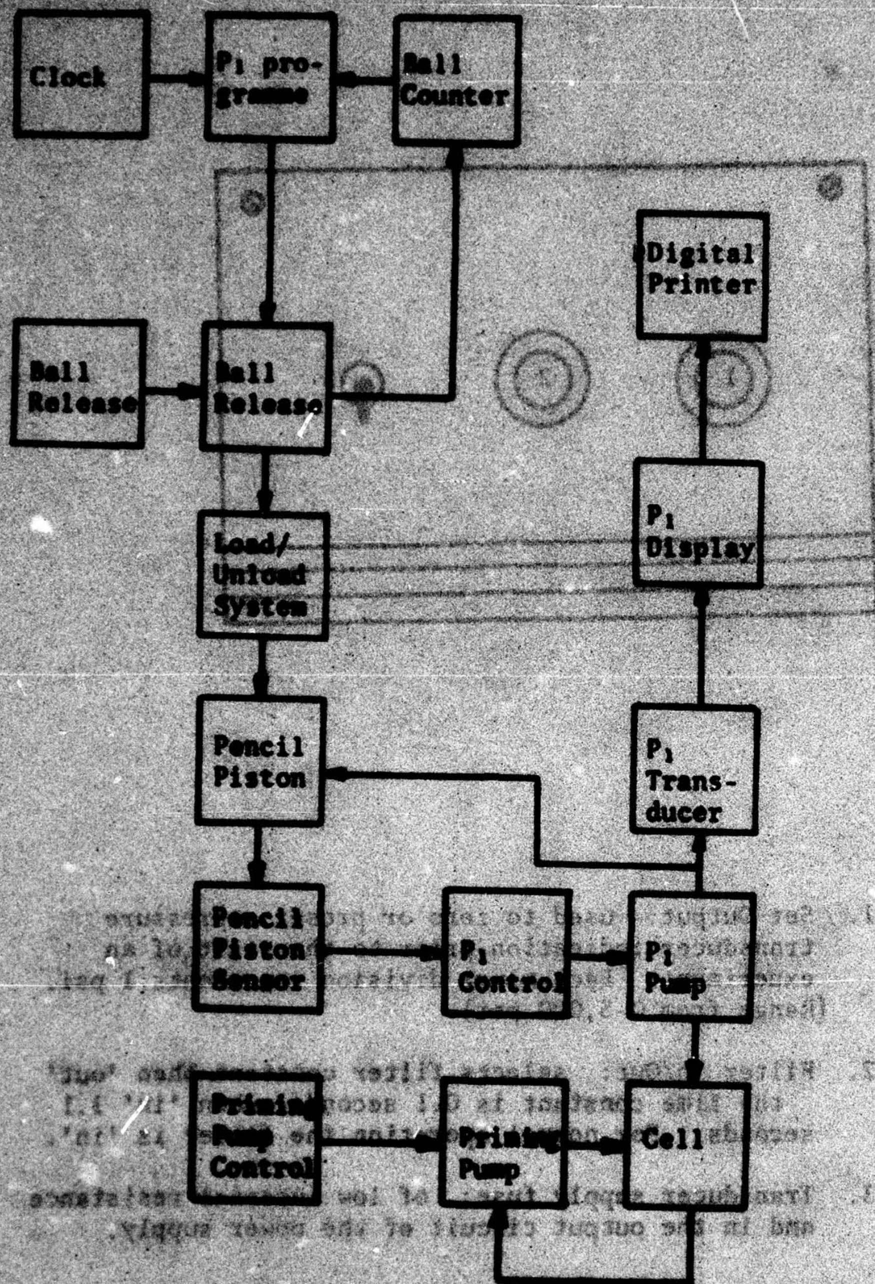
2.3.2 *Pore water (u_2) system*

The pressure of pore fluids within the sample is measured by a pressure transducer. Because the difference between the axial P_1 pressure and the pore pressure is of considerable significance to the consolidation of granular materials the output from the P_1 and u_2 pressure transducers have been filtered and amplified so that they may be visually displayed on digital volt meters and automatically recorded on a data logger.

The control panel for this is shown on Fig. 2.15.

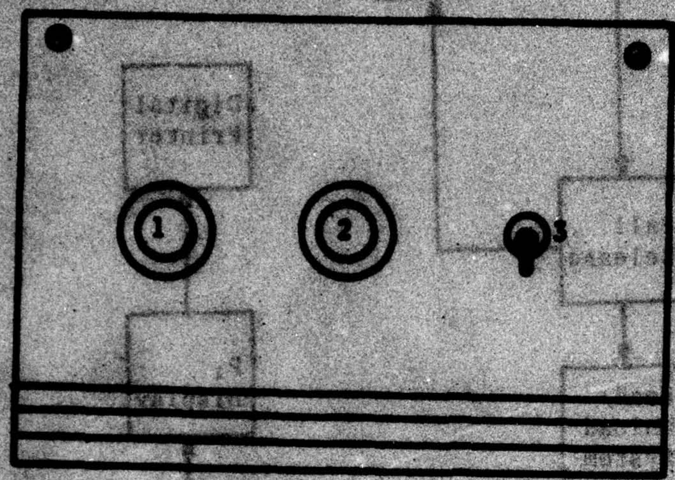
2.3.3 *The measurement of consolidation*

The consolidating specimen results in the specimen cup



P_1 System as Block Diagram

Fig. 2.14



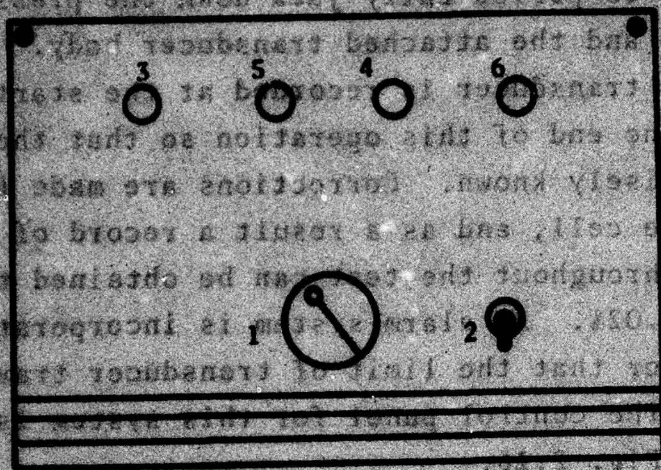
1. **Set Output:** used to zero or preset a pressure transducer indication prior to the start of an experiment. Each minor division represents 1 psi. (Range from 0-5,000 psi).

2. **Filter In/Out:** selects filter constant. When 'out' the time constant is 0.1 seconds: when 'in' 1.1 seconds. For normal operation the filter is 'in'.

3. **Transducer supply fuse:** of low internal resistance and in the output circuit of the power supply.

Control Layout for U_z

Fig. 2.15



1. **Adjust Limit: preset control sets the ± displacement. Limits beyond which the alarm is initiated. (The limits being from 0 to ± 0.5")**

2. **Alarm: used to turn the alarm off if it has been activated either by the displacement transducer being out of limit or by maximum consolidation being achieved.**

3. **Displacement Output Connector: an extension point for connecting a remote meter if required. 1 volt represents 0.1" of movement.**

4. **Alarm: connector which is an extension point for the connector of an extension speaker remote from the laboratory. The extension speaker impedance should be 35 ohms.**

5. **Adjust Transducer: connector which provides a logic output to indicate that the displacement transducer is out of range. (+15V for normal operation, -15V for maximum consolidation occurred.)**

6. **Maximum Consolidation: connector which provides a logic output to indicate that maximum consolidation has occurred.**

Displacement Monitor Control Layout

Fig. 2.16

and this displacement is measured using a linear displacement transducer of 0.6 inches travel. The armature is attached to the top of the specimen cup whereas the transducer body is attached to the pressure balanced piston. As consolidation is generally greater than 0.6 inches it is necessary to periodically jack down the pressure balanced piston and the attached transducer body. The output from the transducer is recorded at the start, during and at the end of this operation so that the new position is precisely known. Corrections are made for the extension of the cell, and as a result a record of specimen consolidation throughout the test can be obtained to an accuracy of ± 0.02%. An alarm system is incorporated to warn the operator that the limit of transducer travel has been reached. The control panel for this system is illustrated in Fig. 2.16.

2.3.4 *Other facilities*

(a) Data logger. A 25 column Bell and Howell digital printer provided printed read-out of axial consolidation and compaction pressure, see Fig. 2.11. The accurate clock within the printer is used as the clock for the system. The printer displays four columns of four figures and one column of five figures, the latter being used for recording time of print-out, in minutes from the start of a test, and the former for the parameters mentioned above. The printer can be used either manually, or, as is more usually the case, automatically; in the latter readings can be recorded at intervals of 0.1, 1, 10, 20 and 100 minutes, according to the rate selected.

(b) Alarm. In order to alert the operator that the limit of travel on the displacement transducer measuring compaction has been reached, an alarm was installed. The alarm can also be used during assembly of the apparatus, at the stage when the armature of the displacement transducer is inserted into the transducer itself.

(c) Power supply. In order to prevent unscheduled termination of a test due to a power failure in the mains supply a set of 12v. D.C. batteries were

installed together with inverters to provide 250v. A.C. supply to the equipment. This system was not automatic, being manually activated when a power failure occurred.

2.4 Electrical systems available; August 1976

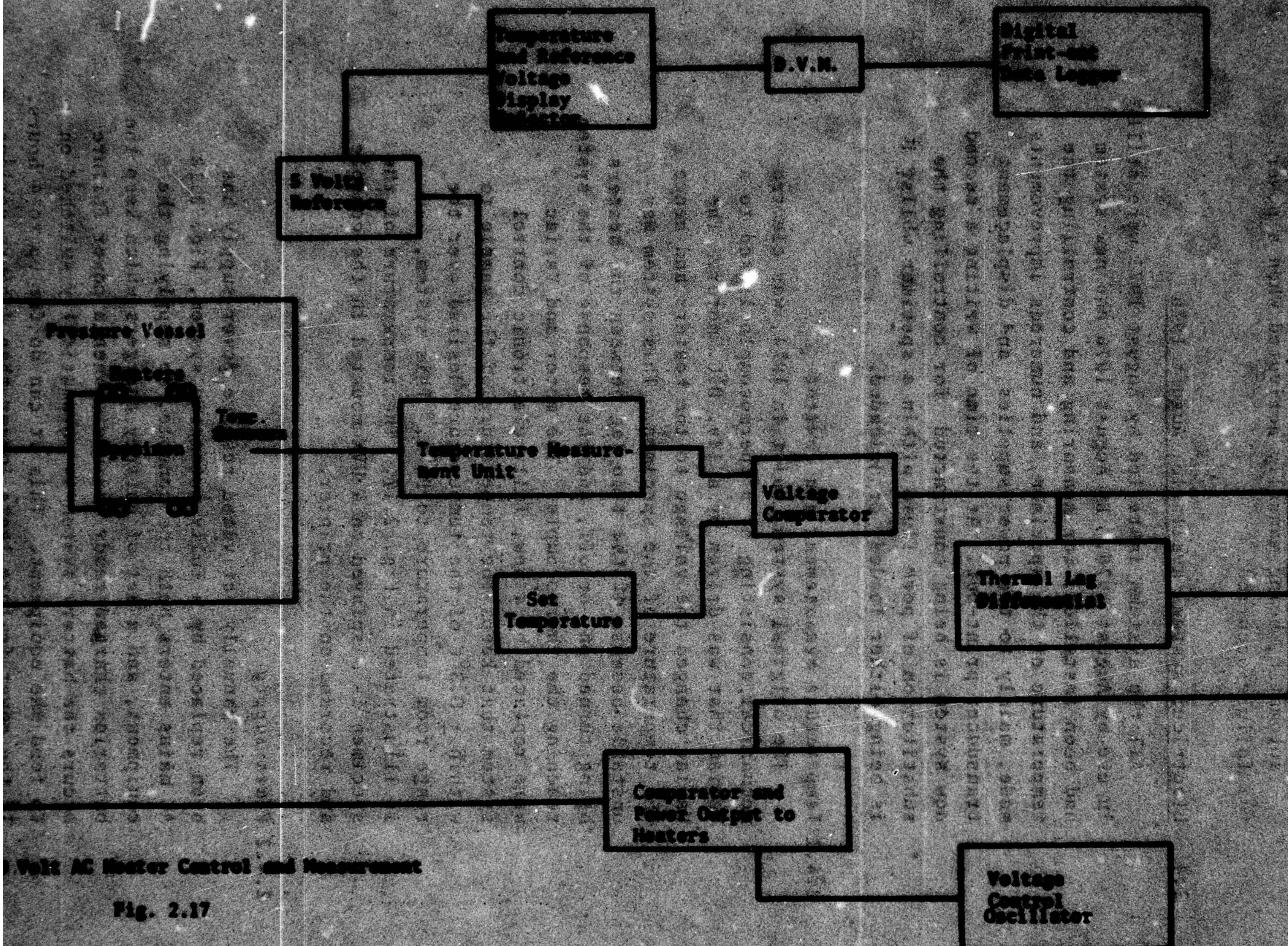
All the systems installed by August 1973 were still in use by August 1976. By August 1976 one new system had been installed, for measuring and controlling the temperature of the specimen, and numerous improvements made, mainly to the power supplies. and displacement transducer print-out. At the time of writing a second new system is being constructed. for controlling the substitution of pore fluid within a specimen whilst it is being either loaded. or unloaded.

2.4.1 *Temperature measurement and control*

The original system, built in 1974, was electro-mechanical, consisting of a thermocouple linked to a Variac that was driven by a 14v. D.C. motor. The Variac changed the voltage to the heaters and hence the temperature of the specimen. This system was unstable because of the time lag between the heaters being turned on, or off, and the response of the system reaching the thermocouple. The motor and Variac were replaced by a new, fully electronic control system that keeps the temperature of the sample to within $\pm$ 0.3^{o}C of the temperature desired over the range room temperature to 90^{o}C. This system, is illustrated in Fig. 2.17. The temperature of the specimen is displayed on a DVM mounted in the console. and recorded on the printer.

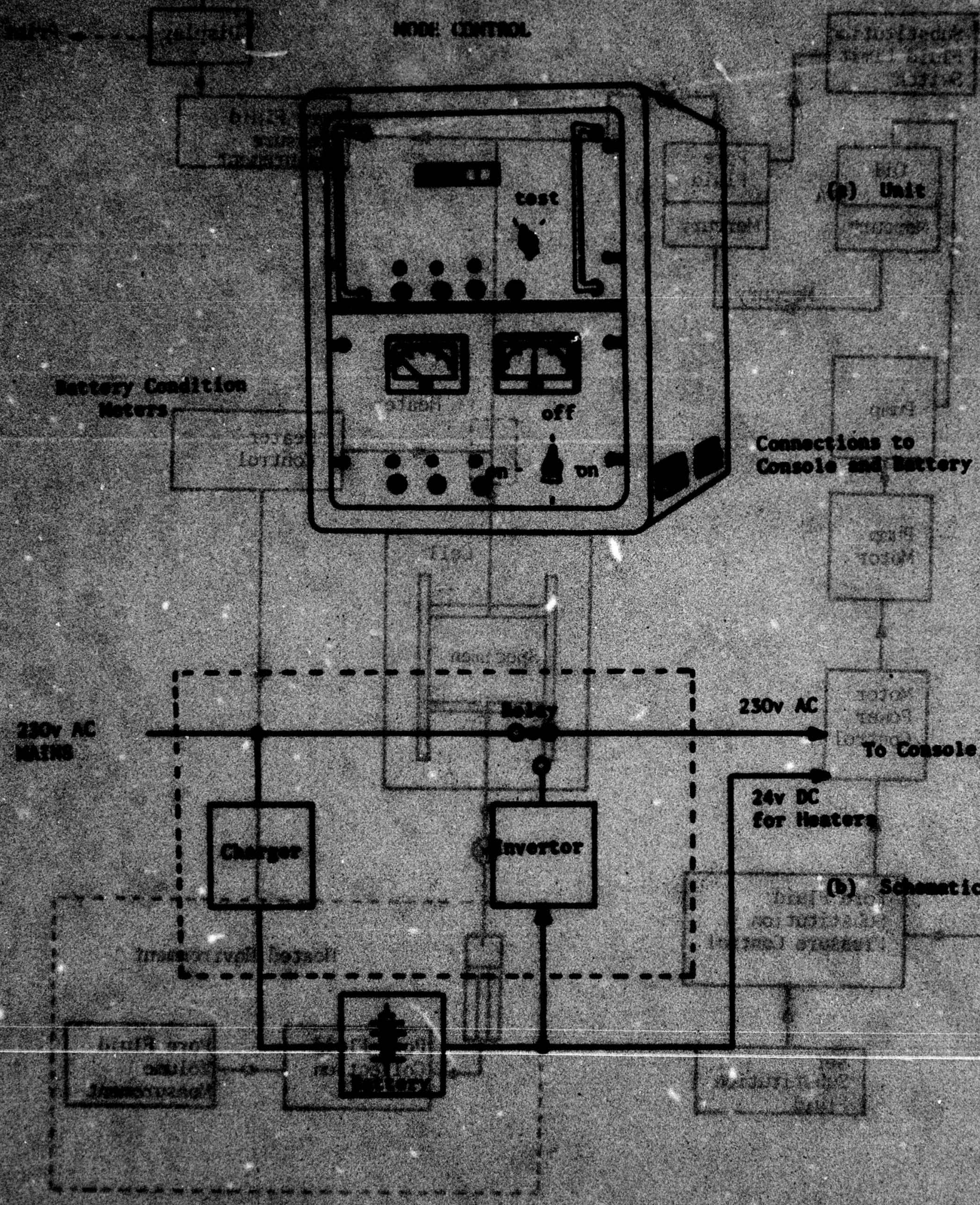
2.4.2 *Power supply*

The manually activated reserve power supply has been replaced by a fully automatic system, Fig. 2.18. AC mains enters both the console, so supplying the equipment, and a set of battery chargers which keep the batteries charged ready for use. When a power failure occurs the battery system is automatically switched on to feed the equipment. This it can do for up to 4 hours. If the power failure lasts longer than 4 hours various



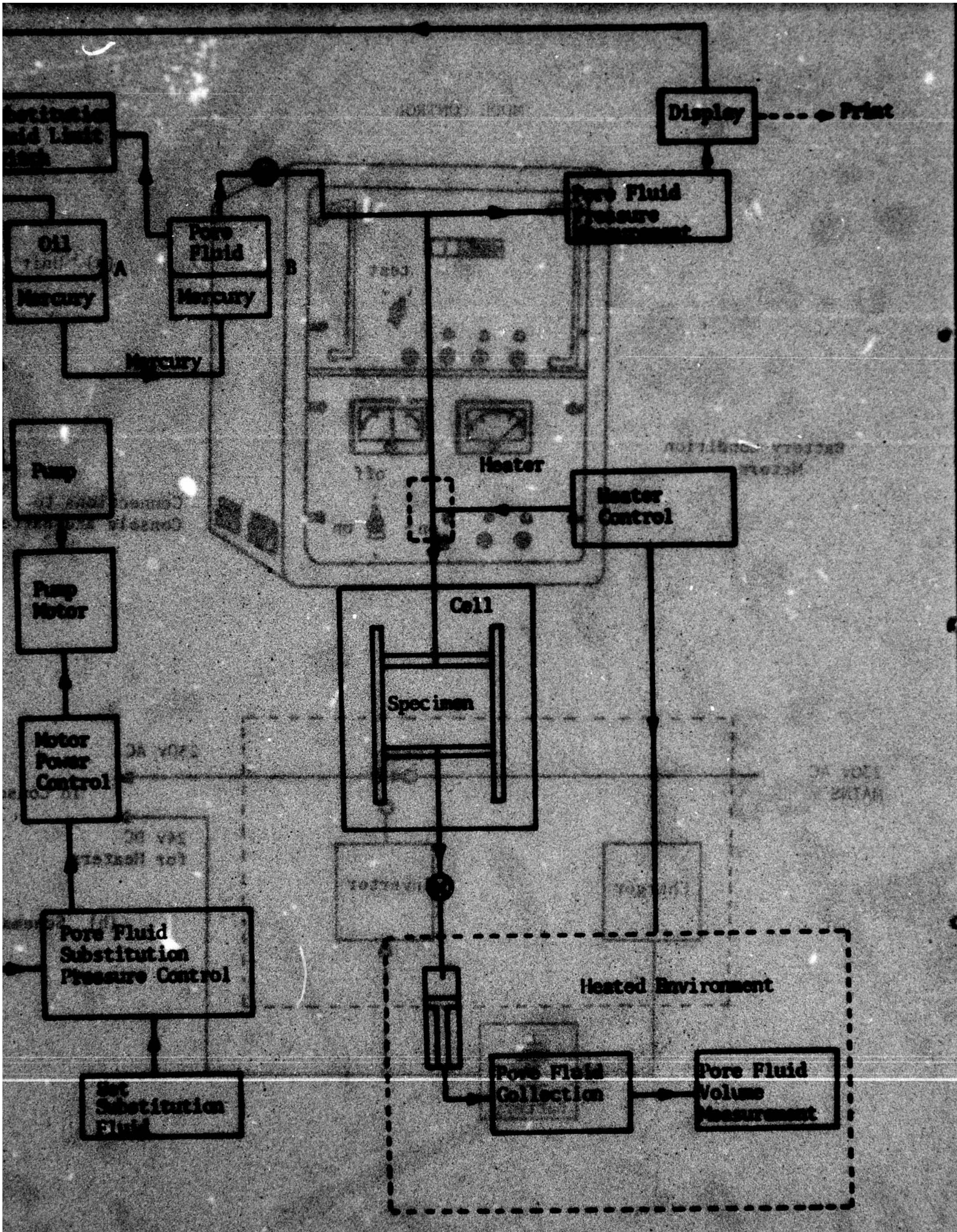
0 Volt AC Heater Control and Measurement

Fig. 2.17



[illegible] Power Supply

Fig. 2.18



A and B = exchange vessels

Substitution System (proposals)

Fig. 2.10

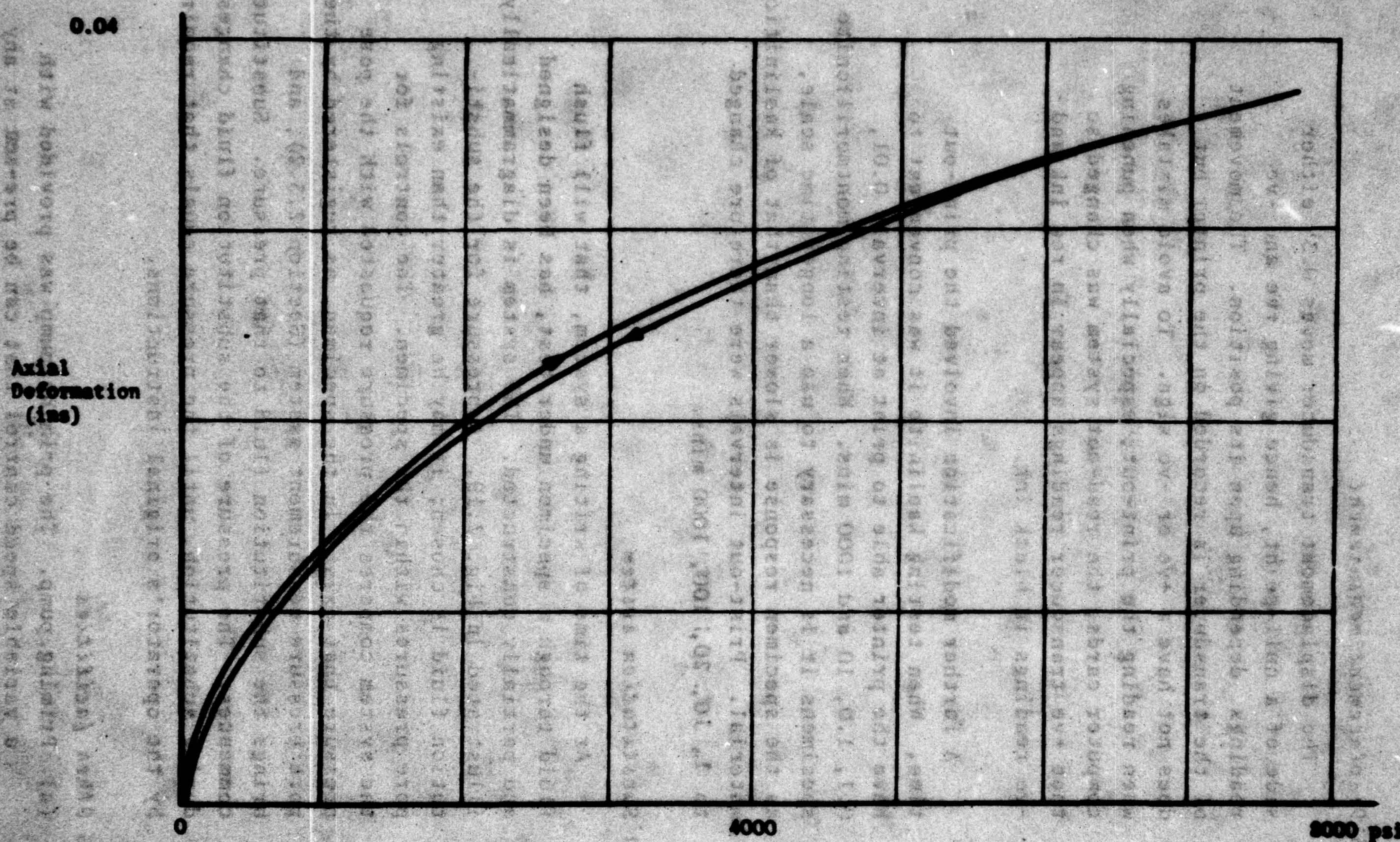
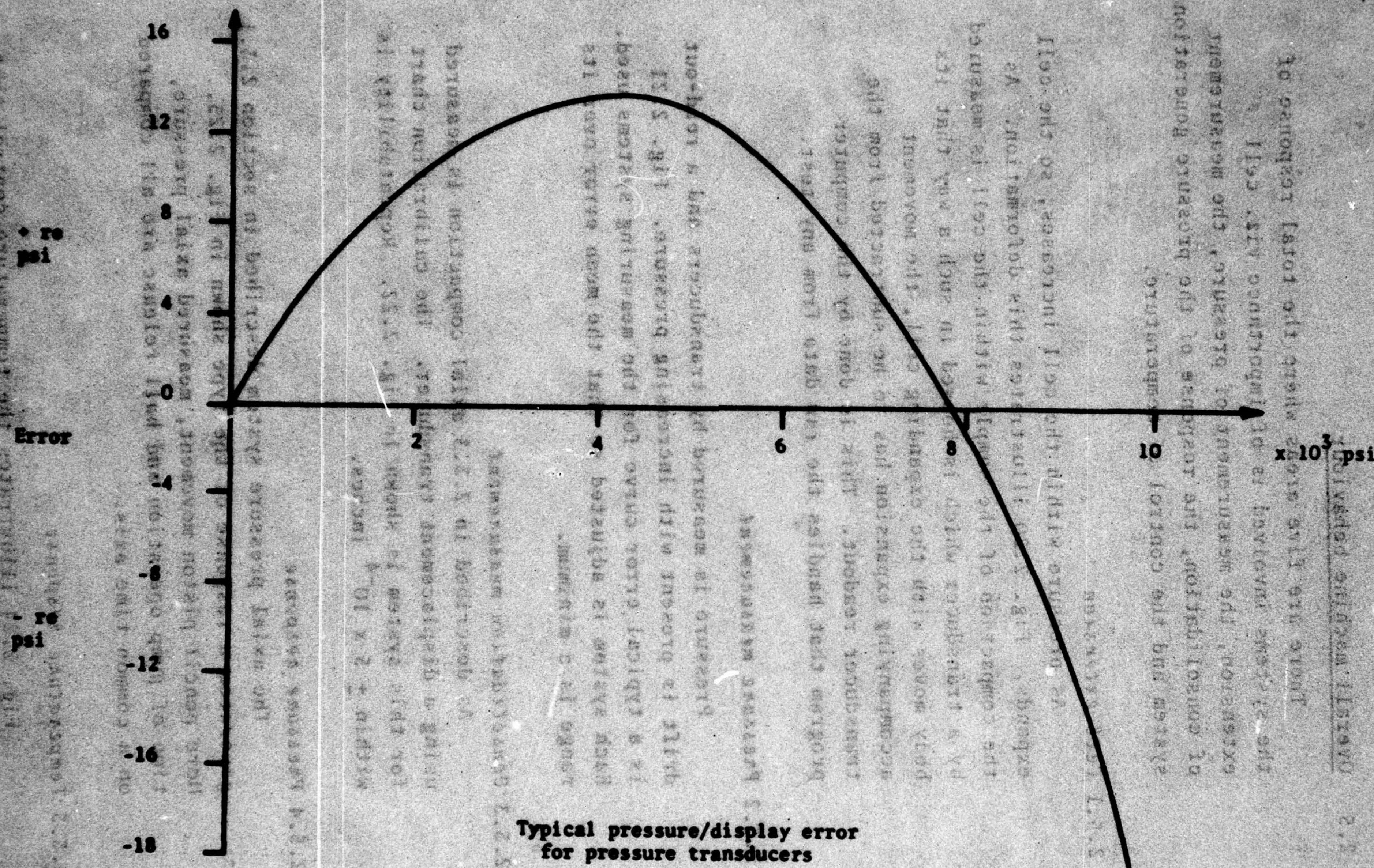


Fig. 2.20



Typical pressure/display error
for pressure transducers

Fig. 2.21

equipment prior to testing and the initial stages of loading.

2.5 Overall machine behaviour

There are five areas where the total response of the systems involved is of importance viz. cell extension, the measurement of pressure, the measurement of consolidation, the response of the pressure generation system and the control of temperature.

2.5.1 *Cell extension*

As pressure within the cell increases, so the cell expands. Fig. 2.20 illustrates this deformation. As the compaction of the sample within the cell is measured by a transducer which is housed in such a way that its body moves with the expanding cell, the movement accompanying expansion has to be subtracted from the transducer readout. This is done by the computer program that handles the raw data from any test.

2.5.2 *Pressure measurement*

Pressure is measured by transducers and a read-out drift is present with increasing pressure. Fig. 2.21 is a typical error curve for the measuring systems used. Each system is adjusted so that the mean error over its range is a minimum.

2.5.3 *Consolidation measurement*

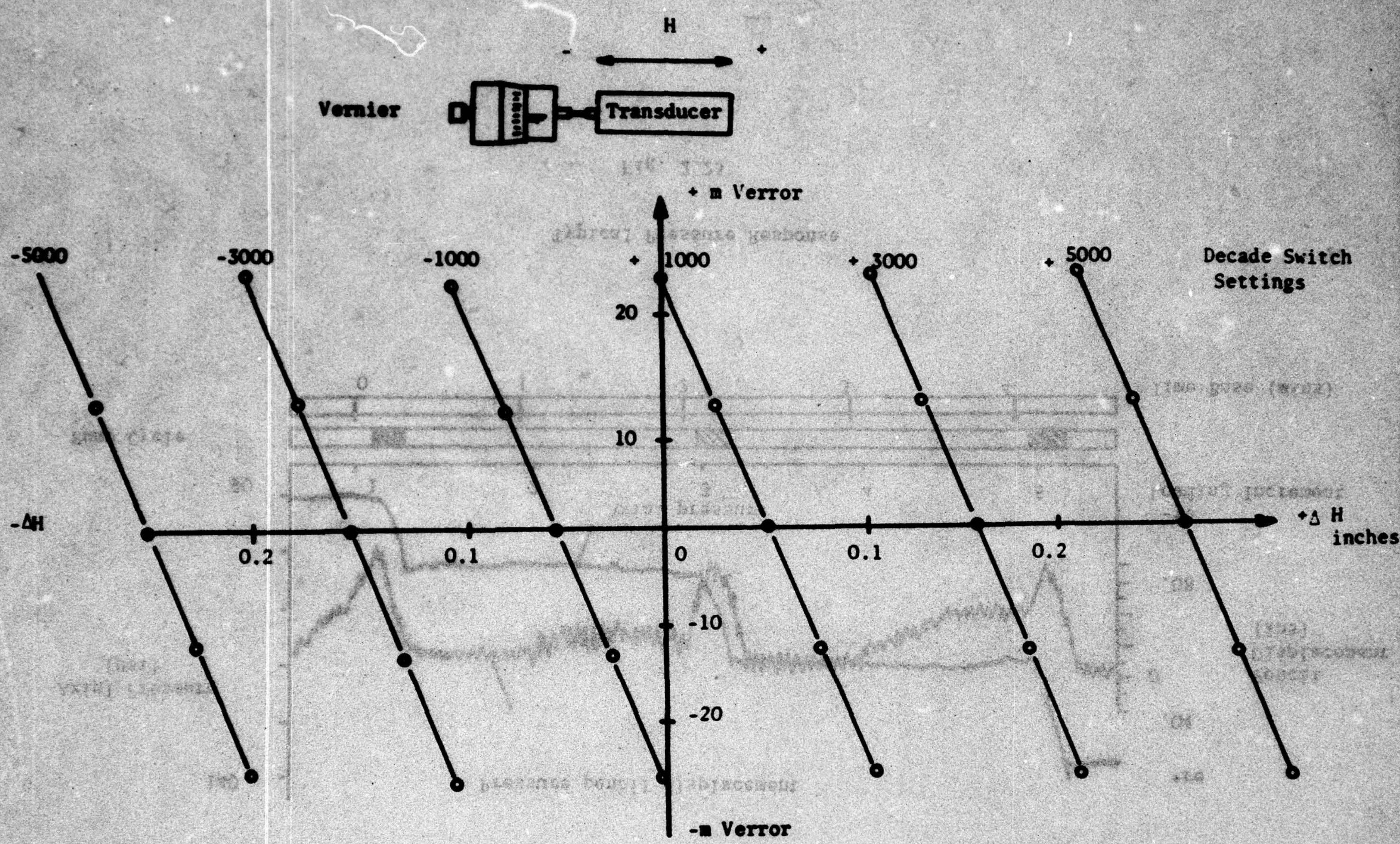
As described in 2.3.3 axial compaction is measured using a displacement transducer. The calibration chart for this system is shown in Fig. 2.22. Repeatability is within $\pm$ 5 x 10^{-4} inches.

2.5.4 *Pressure response*

The axial pressure system described in section 2.3.1 generates a response of the type shown in Fig. 2.23.. Here pencil piston movement, measured axial pressure, time of pump operation and ball release are all compared on a common time axis.

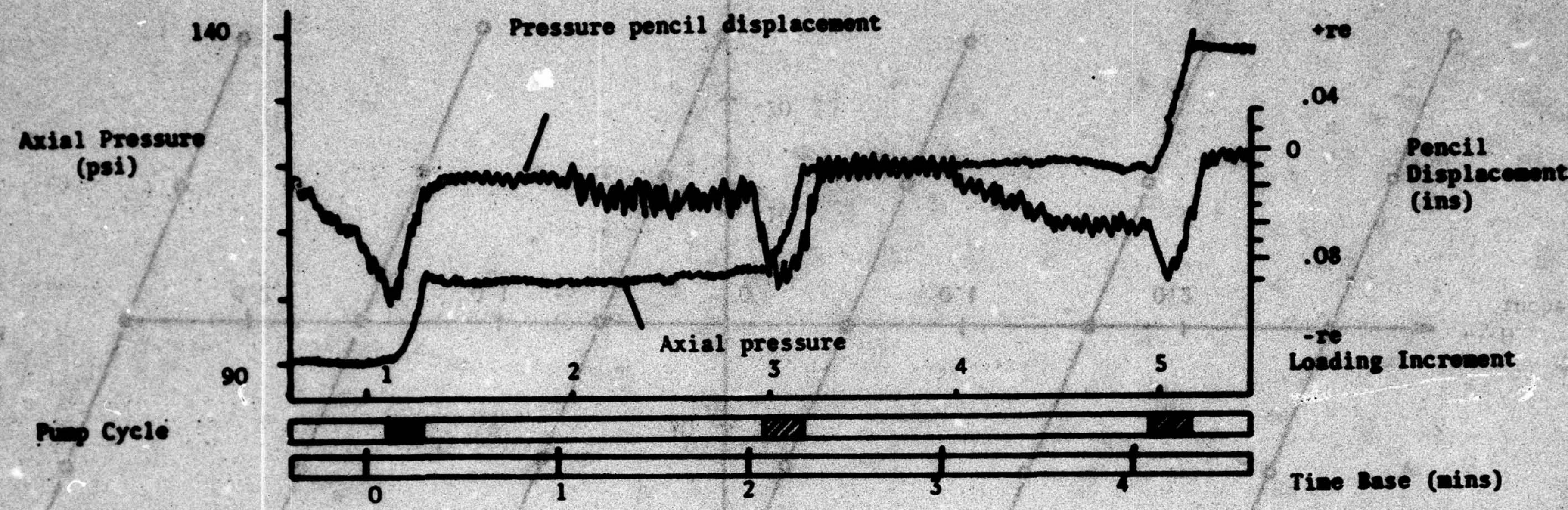
2.5.5 *Temperature response*

Fig. 2.24 illustrates the temperature control that



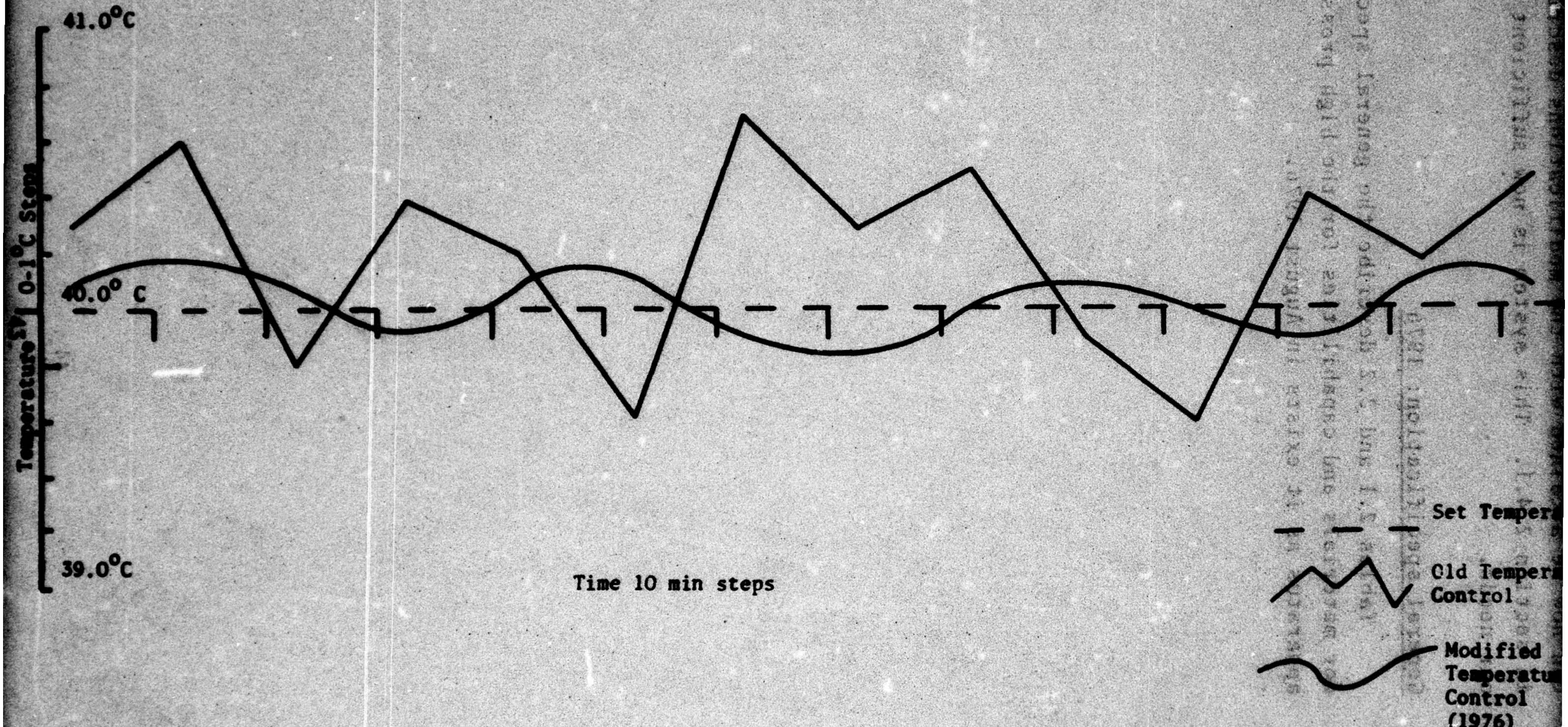
Displacement Transducer Calibration

Fig. 2.22



Typical Pressure Response

Fig. 2.23



Temperature Control

Fig. 2.24

can now be attained with the modifications described in section 2.4.1. This system is now sufficient for our needs.

2.6 General specification: 1976

Tables 2.1 and 2.2 describe the general specification for materials and capabilities for the high pressure apparatus as it exists in August 1976.

Specification of Cell components: August 1976

MATERIAL	RELEVANT INFORMATION	USE
Wrought Steel	B.S.* 970,(1955) En 26 British Steel Corpn. 0.2% proof stress 44 L.T./in^2 (7.0×10^3 kg/cm^2) Ultimate tensile strength 60 L.T./in^2 (9.5×10^3 kg/cm^2)	Pressure Vessel
Low Expansion 36% nickel steel	Henry Wiggin NILO 36 0.2% proof stress (20°C)16 L.T./in^2 (2.5×10^3 kg/cm^2) 0.2% proof stress (200°C)7 L.T./in^2 (1.1×10^3 kg/cm^2) Young's modulus 20×10^6 psi (1.406×10^6 kg/cm^2) Thermal conductivity 0.025 cal/cm sec°C Thermal expansion (mean linear 20-200°C) 2.6×10^{-6}/°C	Specimen cup wall dilatometer band axial compaction transducer support shaft
Low impurity austenitic stainless steel	B.S.** 970,(1955) En 58J British Steel Corpn. 0.2% proof stress 10 L.T./in^2 (1.5×10^3 kg/cm^2) Good corrosion resistance Available in required form	Pore fluid system, sintered drainage plates, hydraulic valves and fittings, & hydraulic chamber of ram pumps
PTFE	I.C.I.** polytetrafluoroethylene Thermal conductivity 6.2×10^{-4} cal/cm sec°C Low sliding friction Stable to greater than 200°C	Specimen cup wall, wall liner, wiper blades and co-axial seals
PTFE-impregnated glass cloth	Fothergill & Harvey 'Tygadure' Good stability in oil at 200°C Low thermal conductivity	Heat baffles in pressure vessel

TABLE 2.1 (continued on next page)

MATERIAL	RELEVANT INFORMATION	USE
Epoxy-resin	Du-pont Adiprene L10C Pure 2-component Urethane rubber Max. working temp 121°C Hardness 90 IRHD*	Main seals in pressure vessel
Viton rubber	Du-pont Viton B. Dowty Seals Ltd. Fluorinated hydrocarbon polymer Working temp. range to +200°C Hardness 75 IRHD*	O-ring seals, U-seals, and co-axial seals
Hydraulic fluid	I.C.I.* 'Silcodyne 'H' Branched chain pure methylchlorophenol silicone Molecular weight range 800-6,000 Coeff. expansion 9.0×10^{-4} ml/ml°C Mean bulk modulus 5000 psi at 100°C Speciffc gravity 1.07+1.10 at 20°C	Main hydraulic system
Hydraulic fluid	I.C.I.* Silicone F 111/20 Linear dimethul polysiloxanes Molecular weight range approx. 800-5,000 Coeff. expansion 10.7×10^{-4} ml/ml°C Specific gravity 0.956 at 20°C	Pore fluid storage system

* I.C.I. Imperial Chemical Industries
IRHD Indentation Rubber Hardness Durometer
B.S. British Standard

TABLE 2.1

Specification of cell capabilities: August 1976

Specimen	diameter	4.0 inches
	maximum initial thickness	4.0 inches
	minimum final thickness	1.0 inches
	pore fluid drainage route volume	0.155 cubic inches
Axial Pressure, P_1	range	0-10,000 psi
	rate of change	1-120 psi/hr
	control accuracy	$\pm$ 0.02%
	control long-term drift	$\pm$ 0.02% max.
	display accuracy	$\pm$ 0.2%
	display long-term drift	$\pm$ 0.1%/month
Axial Consolidation, ΔH	range of rates	0-0.5 inches/day
	monitor accuracy	$\pm$ 0.02%
	monitor resolution	$\pm 1 \times 10^{-5}$ ins.
Pore Fluid Pressure, u_z	range	0-5,000 psi
	display accuracy	$\pm$ 0.2%
	display long-term drift	$\pm$ 0.1%/month
Consolidation Cell	weight of outer tubes	200 lbf
	total weight, assembled	500 lbf
Temperature (t)	range	0-100°C
	rate of change	0-15°C/hour
	control	$\pm$ 0.3°C max
	long term drift	$\pm$ 0.3°C max
	display accuracy	$\pm$ 0.2%
	display long term drift	$\pm$ 0.1%
Pressure source	pencil piston diameter	0.125 inches
	pencil piston travel	0.75 inches
	pencil piston deadband	0.03 inches
	steel ball diameter	0.75 inches
	steel ball weight	0.0622 lbf
	ball stack capacity	500 balls
Pressure compensation ram pump	range	0-10,000 psi
	maximum delivery rate	$0.1 \times 10^{-}$[illegible] ins^3/sec
	swept volume	60 ins^3

TABLE 2.2

3. OTHER EQUIPMENT

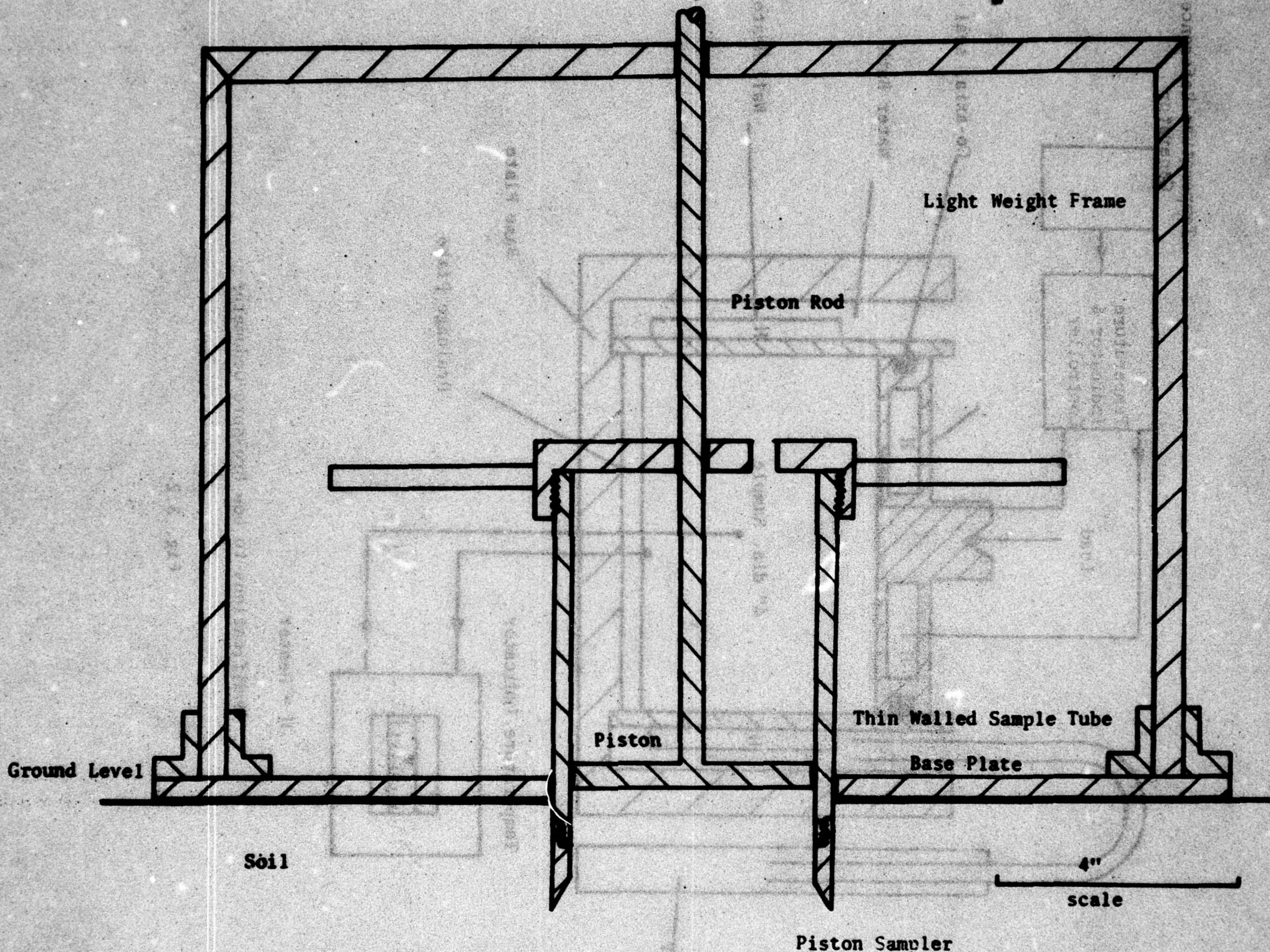
In addition to the high pressure equipment described in Chapter 2 four items of ancillary equipment have been manufactured and modified to assist the collection and testing of material for the project.

3.1 Piston sampler

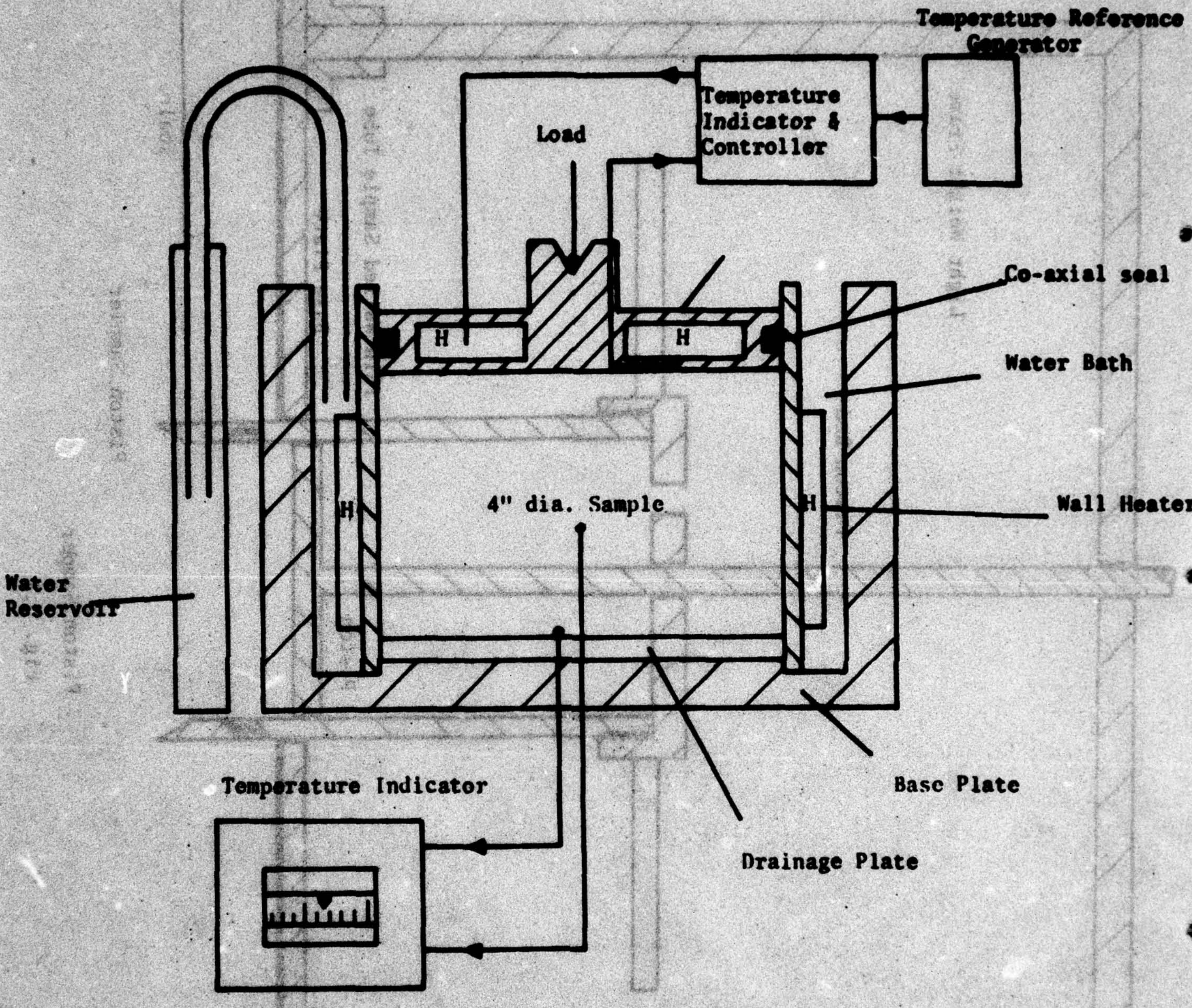
Fig. 3.1 illustrates the sampler that was made for collecting undisturbed specimens of recently deposited sediment. A lightweight frame locates on a supporting metal base that is big enough to spread the weight of the operator over the sampling area. Through this base passes a thin walled sample tube of 4" internal diameter; walls ⅛" thick. Into the tube fits a piston. The cutting edge of the tube, and the lower face of the piston are both placed on the upper surface of the ground. The tube is then gently pushed by hand into the ground. Piston and tube are then retracted and the piston used to extrude the sample, if the sample is not to stay within the tube.

3.2 Low pressure oedometer

Standard low pressure oedometers, as described in BS 1377 (1957) have been modified to investigate the influence of temperature on the consolidation of clay and to simulate, in several respects, the conditions that could be expected in the high pressure apparatus. Fig. 3.2 diagrammatically illustrates the apparatus as used. The mechanical problem to be studied was the performance of the seals. A co-axial PTFE seal, similar to that later used in the high pressure equipment was proved to be adequate. Further it prevented drainage occurring around the loading cap, thereby forcing all drainage to occur via the drainage plate at the base of the sample as occurs in the high pressure equipment. Heating was initially supplied by an element located in the loading platten. Later a second heater was located in the water bath surrounding the sample. Temperature gradients within a sample had been calculated and two thermocouples were used to check the results, one situated at the centre of the sample the other at its base. Suitable controls enabled the temperature of the sample to be either held constant or to change at a constant rate.



Piston Sampler
Fig. 3.1



H = Heater

Modifications to Low Pressure Oedometer

Fig. 3.2

3.3 Constant rate of strain cell

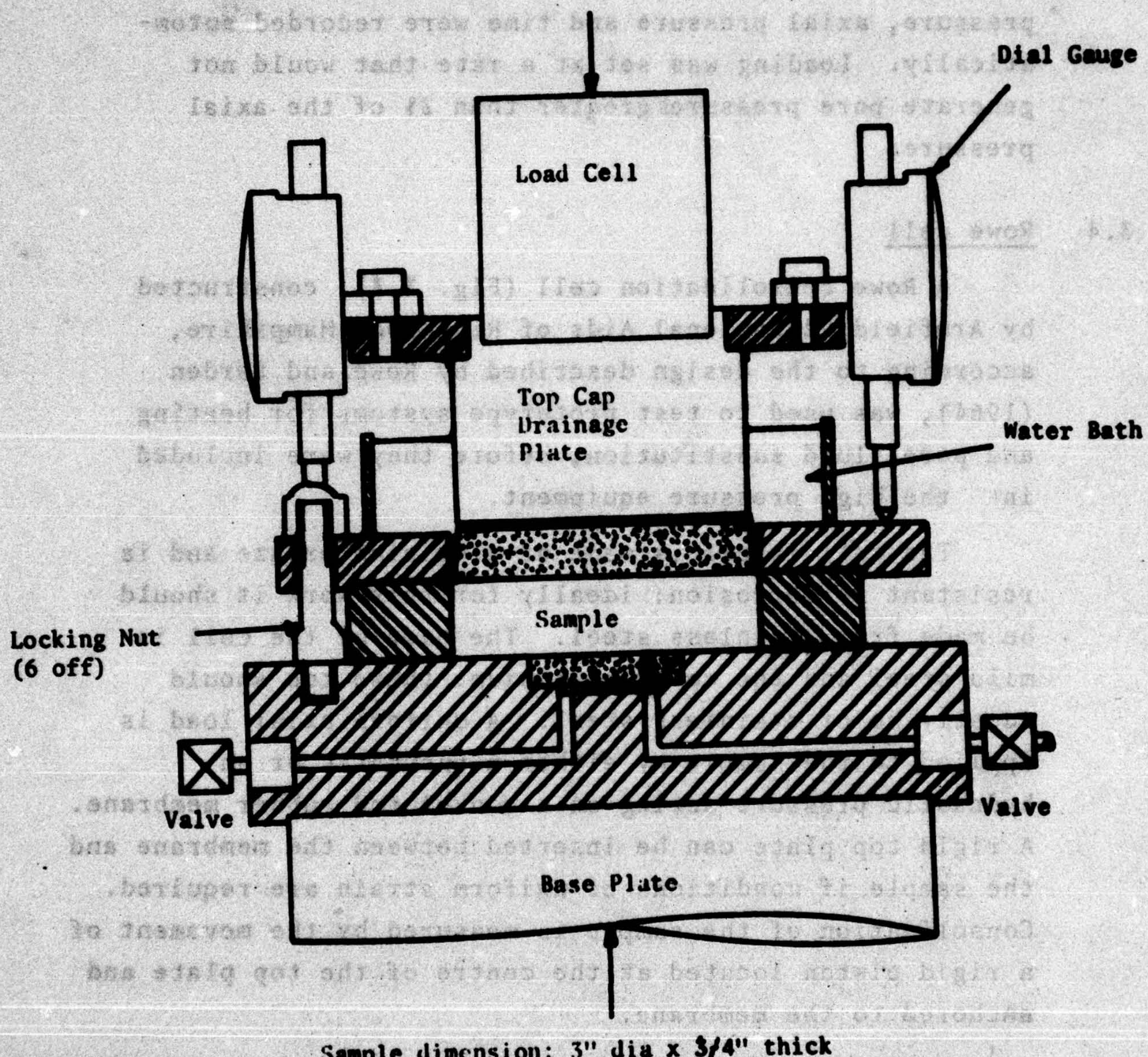
In an attempt to assess the preconsolidation load of certain undisturbed samples, so that values could be compared with those obtained from samples compacted in the high pressure equipment, a cell, similar to an oedometer, was used: Fig. 3.3. This was mounted in a standard loading frame and subjected to loading at a constant rate of strain. Compaction, pore fluid pressure, axial pressure and time were recorded automatically. Loading was set at a rate that would not generate pore pressures greater than 2% of the axial pressure.

3.4 Rowe cell

A Rowe consolidation cell (Fig. 3.4), constructed by Armfield Educational Aids of Ringwood, Hampshire, according to the design described by Rowe and Barden (1964), was used to test prototype systems for heating and pore fluid substitution, before they were included into the high pressure equipment.

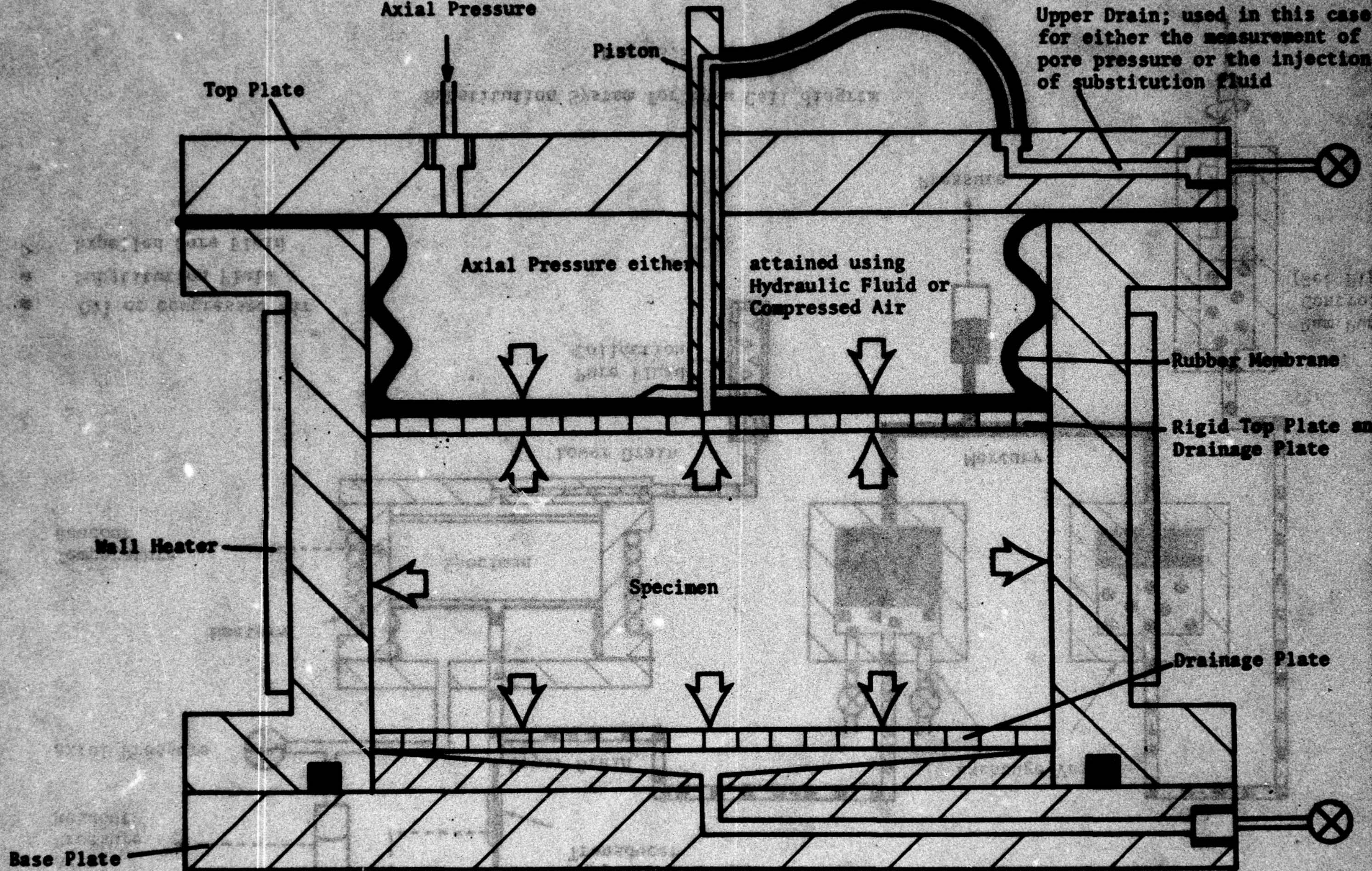
The cell itself is made of aluminium bronze and is resistant to corrosion: ideally for this work it should be made from stainless steel. The base of the cell is mild steel and the cover aluminium: these too should ideally be of stainless steel. A uniform axial load is applied to the sample by either a pneumatic or an hydraulic pressure acting on a convoluted rubber membrane. A rigid top plate can be inserted between the membrane and the sample if conditions of uniform strain are required. Consolidation of the sample is measured by the movement of a rigid piston located at the centre of the top plate and anchored to the membrane.

This basic design has been modified so that pore fluid within the sample can be substituted during a test. Under normal conditions drainage occurs from the base of the sample and pore pressure is measured at the top of the sample. When substitution is operating fluid is injected into the top of the sample and collected at the base of the sample. To drive the fluid through the sample a simple set of exchange vessels are required (Fig. 3.5). To prevent the pore fluids being contaminated by the fluid used for axial



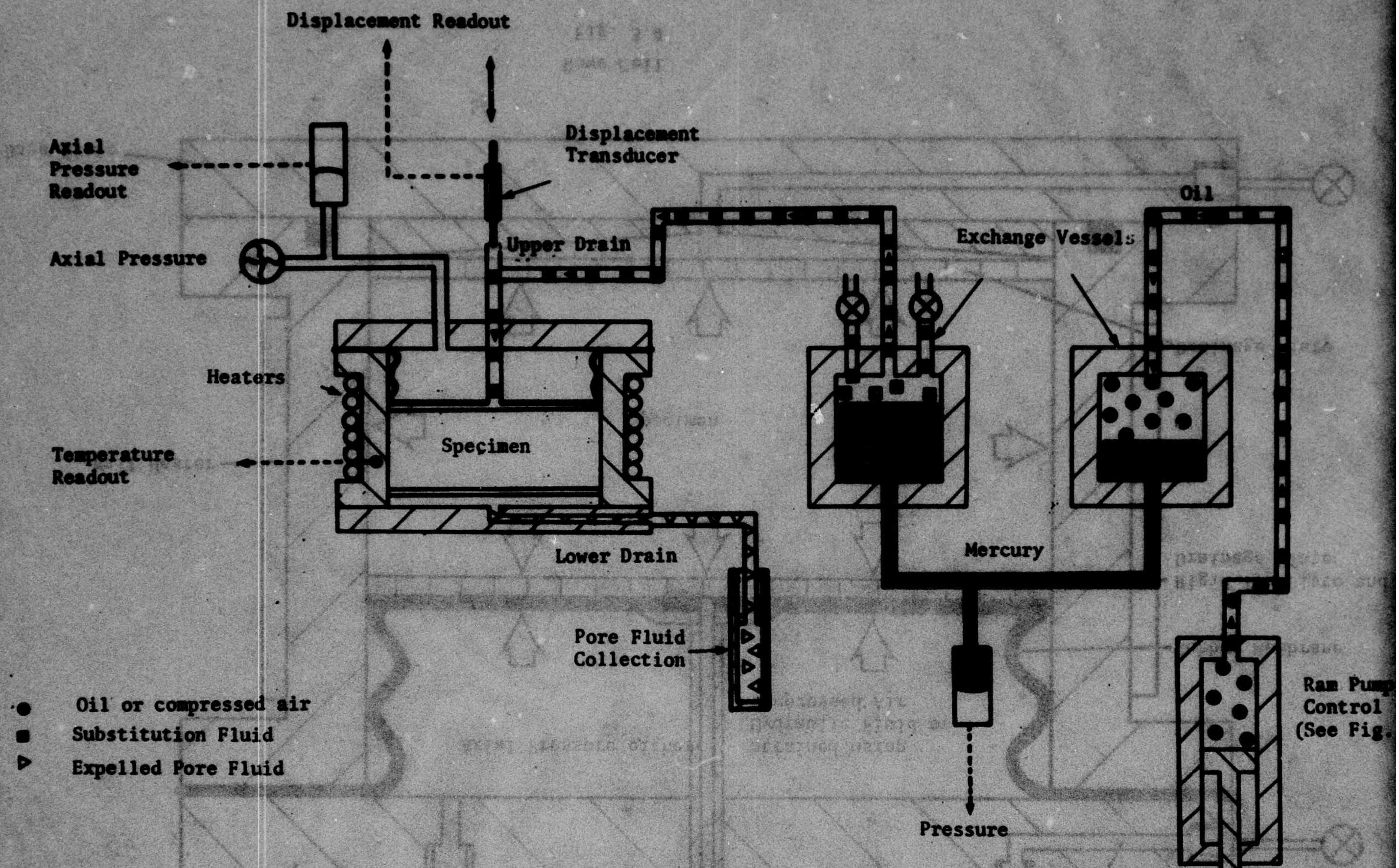
Constant Rate of Strain Cell

Fig. 3.3



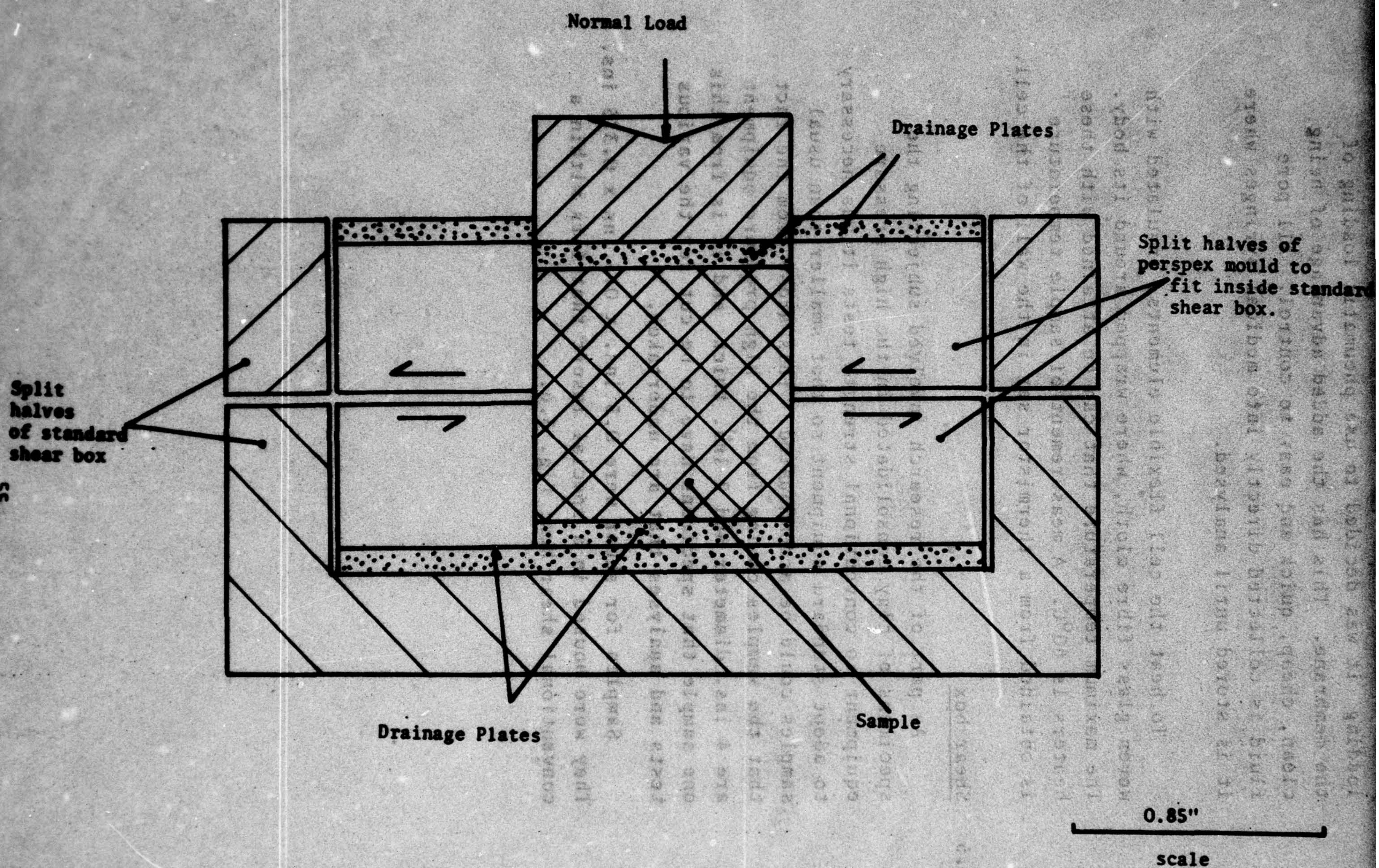
Rowe Cell

Fig. 3.4



Substitution System for Rowe Cell diagram

Fig. 3.5



Modified Shear Box
Fig. 3.6

loading it was decided to use pneumatic loading of the membrane. This has the added advantage of being clean, cheap, quick and easy to control. All pore fluid is collected directly into medical syringes where it is stored until analysed.

To heat the cell flexible elements, insulated with woven glass fibre cloth, where wrapped around its body. The maximum temperature that can be attained with these heaters is 60°C. A measurement of sample temperature is obtained from a thermistor set in the wall of the cell.

3.5 Shear box

As part of the research involved subjecting the specimens of clay consolidated in the high pressure equipment to conventional strength tests it was necessary to adopt standard equipment so that smaller than usual samples could be accommodated. This arose from the fact that the samples coming from the high pressure equipment are 4 ins. diameter and 2 ins. thick: and it is from this one sample that specimens have to be cut for the various tests and analyses that are undertaken.

Samples for shear were 0.5 ins. x 0.5 ins x 0.375 ins. They were housed in a special insert that fits within a conventional shear box: Fig. 3.6.

4. ANALYSIS OF SAMPLES

The analyses conducted during this research have been involved mainly with the study of the solid and liquid products of compacting clayey sediments. Particular attention has been given to the mechanical and textural properties of the compacted sediment, and the chemical character of the fluids expelled from the sediment.

4.1 Facilities available in 1973

The following analytical facilities were available at the commencement of the research contract:

(i) for compaction: High pressure, high temperature oedometer.
Standard oedometers and triaxial cells.

(ii) for strength: Standard soil shear-boxes, and triaxial cells.
Laboratory cone, and vane apparatus.

(iii) for fabric: Scanning electron microscope.
X-ray diffractometer.

(iv) for chemistry: Atomic adsorption spectrometer.
Titration.

(v) for raw data: Imperial College Computer Centre.

The research contract enabled certain facilities to be enhanced, particularly those associated with the analyses of compaction and strength. In addition to this the College facilities, particularly those for chemistry, also improved. Furthermore, contacts outside the College have been strengthened so that the analyses of fabric could be improved.

4.2 Facilities available in 1976

With reference to the previous section, these are as follows:-

(i) for compaction: as in 4.1, but also heated low pressure oedometers,
Rowe Cell, with substitution facilities.

(ii) for strength: as in 4.1, but also special small shear boxes.

(iii) for fabric: as in 4.1 but also use of scanning electron microscope at North East London Polytechnic.
Use of texture goniometer at Leeds University.
Fraunhoffer diffractometer.

(iv) for chemistry: as in 4.1, but also nephelometer equipment.

(v) for raw data: as in 4.1, but also digital printer for high pressure oedometer.
Digital printer for ancillary equipment.

4.3 Samples produced

The compaction tests have been carried out on clay, sand and chalk that has been disaggretated and remoulded in water of a chosen composition. The nature of the specimens after compaction depends on the initial composition and stress history, but generally the material commenced loading in the state of a weak slurry which is gradually changed into a compact mudstone by compression. The resulting specimens are sufficiently consolidated to be picked up by hand without deformation and frequently require cutting with a steel band-saw to extract samples for subsequent examination.

The composition of the various specimens that have been tested are listed in Section 6. The nature of the constituents used in these tests are outlined below:

(i) Ball Clay type 661 obtained from English China Clays Ltd.
(ii) Undisturbed Ball Clay collected from Devon.
(iii) Montmorillonite as Fuller's Earth type SYP No. 1 obtained from Laporte Industries Ltd.
(iv) Chalk collected from the Upper Chalk at Radlett, Herts.
(v) Sand obtained from Hopkin & Williams in the form of acid washed sand type 749600.

The clay, sand or chalk was remoulded in water that was prepared in the laboratory in order to reproduce various

conditions of salinity. The composition of this water was controlled by preparing it from known quantities of chemicals added to distilled water. The water was first de-ionized and before being used it was de-aired under a vacumm of 0.5 Torr. The types of water can be summarized as follows:

(i) Distilled water.

(ii) Saline water used in the BCCHP series of tests. This was used in three concentrations corresponding to x½. x1 and x2 that of natural seawater. The unit saline water corresponded to an ionic chemistry of Na^{+} 10.5, K^{+} 0.4, Ca^{2+} 0.3, Mg^{2+} 1.2, SO_4^{2-} 2.5 and Cl^{-} 19.0 g/l

(iii) Saline water used in the FE series of tests corresponded to a composition of Na^{+} 10.5, K^{+} 0.4, Ca^{2+} 0.4, Mg^{2+} 1.3, SO_4^{2-} 2.7 and Cl^{-} 19.1 g/l.

Each test produced one compacted sample of clay. Tests conducted in the high pressure oedometer and Rowe Cell (Chapter 3) enable the interstitial water, that is expelled from the sample during compaction, to be collected.

4.4 Collection and storage of samples

The compacted soil specimens were carefully extracted from the consolidation apparatus at the end of each test by splitting the upper tube from the lower tube and allowing the lower tube to slide down the lower plug, so exposing the specimen cup from which the specimen can be removed. The weight and physical dimensions of each specimen was measured and samples taken for moisture content before sealing the specimen up in aluminium foil and coating with wax. This prevented loss or absorbtion of water by the specimen and preserved it for future examination.

The pore fluids expelled during consolidation were collected in syringes inserted into the drainage plate of the apparatus and stored in the syringe bottles. The bottles containing the fluid were refrigerated at 5°C until required for chemical analysis. This inhibited any chemical reactions taking place within the fluid or exchange of ions between the fluid and the walls of the bottle.

4.5 Soil testing

The best method to simulate the general effects of diagenesis of argillaceous sediments in the laboratory is to compact specimens under controlled conditions of pressure and temperature where the initial state of the specimen is known. Variations of physical and chemical properties are then monitored as compaction takes place.

The main item of equipment that has been used is the specially designed high pressure and temperature consolidation apparatus described in Chapter 2. This is capable of compacting samples of 100 mm initial length in a cylinder 100 mm in diameter over a range of pressure from 0 to 70 MN/m^2 and temperatures up to $80^{\circ}C$. Facilities exist for continuously monitoring axial pressure, pore fluid pressure, degree of compaction, temperature and for the substitution of pore fluid through the specimen and sampling of expelled pore fluids.

Because of the long time taken by each test (of the order of two months per test) it was decided to carry out similar tests in a comparatively low pressure consolidation apparatus to provide information on the processes taking place during the early stages of diagenesis. The apparatus used was a Rowe Cell that had been specially modified for this research project by providing pore fluid substitution, pore fluid sampling and facilities for heating the specimen up to $60^{\circ}C$ (Chapter 3). The axial pressure could be applied from 0 to 850 kN/m^2 and the same features could be monitored as on the high pressure equipment. However, larger specimens could be handled in the Rowe Cell of up to 75 mm initial thickness and 250 mm in diameter.

In order to carry out comparatively rapid testing programmes to assess the behaviour of a testing medium to changes in single parameters such as temperature, moisture content and mixtures of different proportions with an inert filler to increase permeability, two oedometers were designed and constructed. Both these oedometers were capable of testing specimens up to an initial thickness of 25 mm and 100 mm diameter, and one was designed with end and wall heaters to

carry tests out at elevated temperatures up to 70°C. The walls and pistons of each oedometer were lined with PTFE in order to reduce friction to a minimum and to minimise the effects of apparatus expansion during high temperature tests. Standard oedometers were also used in the testing programme to compare the results of the other non-standard tests with those which could be obtained using the normal routine testing in soil mechanics practice. The standard oedometers consolidate samples of 75 mm diameter and an initial thickness up to 18 mm and allow drainage at both ends of the sample; the previous tests mentioned were set up to allow drainage at one end only .

The measured parameters for each test were processed manually or using the computer as appropriate.

Samples of pore fluid were collected from the high pressure and Rowe Cell tests and their chemistry was subsequently analysed.

The compacted specimens were carefully extracted after the completion of each test and a series of tests and observations systematically carried out. These included measurements of shear strength using a falling cone penetrometer and shear box, fabric using optical microscopy and X-ray techniques, mineralogy using X-ray diffraction, consolidation characteristics using oedometers, moisture content distribution through the specimen and cation exchange capacity.

Additional tests were carried out on the material before testing and these included index tests, moisture content, specific gravity, particle size distribution, mineralogy and cation exchange capacity.

The procedures involved in these testing techniques are outlined below:

4.5.1 *High pressure equipment*

The high pressure consolidation cell forms the main item of testing equipment in the current research programme. The apparatus has facilities for the control of (a) over-

burden pressure, (b) pore fluid pressure and (c) temperature. The specimen is contained in a rigid steel cup assembly which fits onto an anvil (Chapter 3). Capillary tubes allow drainage through the anvil for pore fluid collection and at the opposite end for the measurement of pore fluid pressure and the substitution of new fluids.

A typical assembly procedure for the high pressure tests using montmorillonite in the FB series of tests is as follows:

(i) Soak clay in the fluid of known composition for a period of about one week to allow equilibrium to be obtained and then de-air under a vacuum of 0.5 Torr.

(ii) Assemble specimen cup and insert sintered stainless steel drainage plates which have been saturated with the pore fluid being used in the specimen, the plates are lined with Whatman No. 42 filter paper to prevent clogging from clay particles.

(iii) A sedimentation column 0.5 m high is placed over the specimen cup and filled with de-aired fluid of the same composition as that used for soaking the clay.

(iv) The clay slurry is sedimented through the sedimentation column for 24 hours and the sediment then trimmed to allow the attachment of the top drainage plate.

(v) Attach heating connection and check electrical circuits.

(vi) Raise lower tube of cell until lower plug and specimen cup are in correct position and then raise lower tube close to upper tube.

(vii) Connect pore fluid capillary tube coupling to top of specimen cup.

(viii) Finish raising lower tube, guiding displacement transducer armature into place very carefully.

(ix) Rotate the locking ring to secure the two halves of the cell.

(x) The cell can then be filled with hydraulic oil and priming commenced.

The kaolinitic Ball Clays used in the BC series of tests were prepared in a different way during the initial stages. The remoulded Ball Clays were prepared by mixing the air dried material thoroughly with the appropriate fluid in an electric mixer to a moisture content well above the liquid limit (approx 100%). The clay was then kept in a humid environment for over 48 hours to ensure complete hydration of the clay particles. The slurry was then poured into the specimen chamber which had been previously prepared by flushing the porous plates and lubricating the teflon linings, with a smear of silicone grease. Whatman No. 1 filter paper was used between the specimen and the porous plates to avoid the pores of the latter becoming clogged. The first few tests showed that a specimen having a 100% moisture content was too soft for handling and in the subsequent tests the remoulded clay was preconsolidated within the chamber to about 72% moisture content. As it was intended to observe the fabric of the final specimen, care was taken to ensure similar stress and displacement conditions so the same end of the specimen was allowed to drain and a strain rate equal to the anticipated early rate of strain in a test was used. The preconsolidated specimen was then ready for assembly in the cell as in the FE series.

The undisturbed samples were cut from an undisturbed block by pushing a 100 mm dia. cutting ring into the block, trimming as necessary. The specimen ends were trimmed to give a thickness of about 100 mm and filter papers were placed on both ends. The lower plug of the cell is rested on a supporting stand and the specimen chamber containing the specimen, filter plates and scraper blades, in position, is then inverted carefully onto the lower plug. The testing procedure is then the same as for the FE series.

The equipment has been developed to the point where rates of change of axial pressure (simulated overburden pressure) and temperature can be set and left to run. The axial pressure, pore fluid pressure, temperature and axial consolidation are all measured and recorded automatically.

4.5.2 Rowe Cell

The consolidation cell developed by Rowe and Barden (1964) and called the Rowe Cell has been specially adapted for use in comparing the compaction characteristics of clays in the lower range of stress used in the high pressure equipment. In the basic consolidation cell the total stress is applied by means of hydraulic pressure acting across a convoluted rubber jack. This arrangement improves the control of the drainage conditions allowing the separation of the instant of loading from the commencement of drainage and permitting the measurement of initial pore pressures. The cell has been adapted to allow compaction to take place at temperatures in the range 10-60°C and has facilities for the substitution of pore fluids and the collection of expelled pore fluids during the progress of the test.

The testing programme using the Rowe Cell commenced in December 1975 and Fuller's Earth is the only material to be investigated so far. The samples are prepared by mixing the air dry clay with a pore fluid of known chemical composition in an electric mixer and allowing it to stand for 48 hours to ensure complete hydration of the clay particles. The clay slurry is then de-aired under a vacuum before placing into the Rowe Cell. The top and bottom of the sample are capped with Whatman No. 1 filter papers and sintered bronze porous plates, to protect it from internal erosion during drainage. Equal drainage across the ends of the sample is aided by specially constructed drainage plates, with a network of channels leading to the drainage pipe (Chapter 3).

The system is allowed to prime under a low axial pressure without drainage for a period of 24 hours before commencing the loading cycle of the test. This allows the plates to settle down and the sample to become thoroughly heated to the desired temperature.

The sample compaction, axial pressure and pore fluid pressure are automatically recorded by transducers linked to a data logger. However, the temperature and volume of pore fluid substituted or expelled has to be recorded manually.

The substitution of pore fluids is achieved using a perspex pot linked to the undrained end of the sample. The desired substitution fluid is contained in this pot and pumped into the sample at the required pressure using hydraulic oil via a mercury interface. The pot can be emptied and refilled with fluid during the progress of a testing should the volume prove to be insufficient (see Fig. 3.5).

4.5.3 *Low pressure oedometers without heating*

Two types of oedometer have been used for carrying out consolidation tests. One is the standard 76 mm dia. oedometer with drainage at both ends as described in BS 1377 (1967) and the other is a 100 mm dia. oedometer constructed from PTFE which allows drainage at one end only (Chapter 3). The method of sample preparation and testing is the same for both oedometers, which basically involves consolidation of a sample confined in a ring between two pistons by the application of a dead load via a system of hangers. The axial compaction is measured relative to the base of the cell. The change in compaction is then measured as a function of time after the application of a load increment.

The specimens were prepared from clay, chalk or sand in an air dry condition as for the Rowe Cell tests described earlier. With the fixed ring in place over one of the porous stones, the slurry was placed carefully into the ring to avoid trapping any air. The upper surface of the sample was then smoothed and the loading cap gently placed. The assembly was then lowered into the water bath and the entire cell arranged in position in the loading device. Loading was then commenced by applying increments every 24 hours.

4.5.4. *Low pressure oedometers: with heating*

In order to study the effects of temperature on the consolidation of clays, a pair of oedometers were designed and constructed which were capable of being heated and had very low frictional resistance to the moving components. The specimen chamber is 100 mm in diameter and is constructed with PTFE seals to apply the consolidation load. Drainage is only allowed via a sintered steel drainage plate at the base of the chamber. Heat is applied from ceramic coiled elements around the specimen chamber and a hot plate incorporated in the piston. Two thermocouples sense the temperature at the drainage plate and in the specimen. These control the heaters to maintain the temperature at a constant value or to increase at a chosen rate mechanically via a cam on the heater control unit. The temperatures can be checked during a test by a electronic thermometer.

The specimen cup fits in a standard laboratory oedometer loading frame and tests were carried out using the same procedure described for low pressure oedometers without heating.

Two series of experiments were undertaken in this apparatus. The first was to examine the effects of temperature on the consolidation of identical specimens of montmorillonite and the second was to examine the variation in consolidation of montmorillonite with different initial void ratios. All tests were conducted on montmorillonite slurries remoulded in distilled wator.

4.5.5 *Constant rate of strain consolidation cell*

This technique of consolidation testing was first adopted by Smith and Wahls (1969) and a more versatile general purpose consolidometer was subsequently developed by Wissa et al (1971) at M.I.T. The cell is built from brass and contains a sample 76 mm in diameter and 18 mm thick. The axial load is measured using a load

cell and the pore pressure measured using a pressure transducer connected to a pipe leading from the base of the sample. The axial deformation can also be electrically recorded using a displacement transducer.

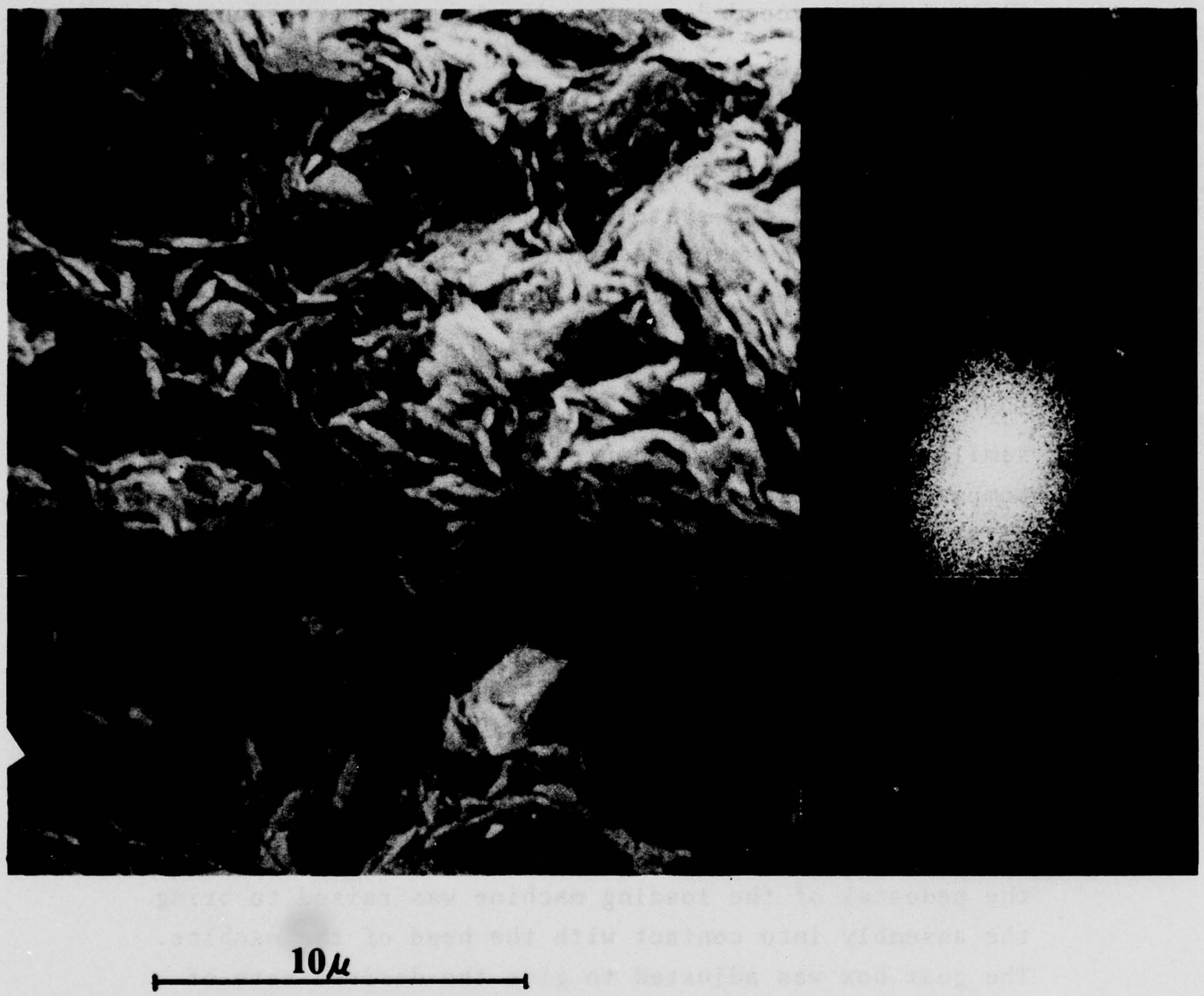
The test procedure was to connect the pore water pressure transducer to one of the outlets from the base of the cell using a Klinger valve. De-aired water was flushed through the system and after closing the other flushing tap, a saturated porous stone 38 mm diameter and 6 mm thick was placed in the recess provided in the base; see Fig. 3.3.

The undisturbed specimens were prepared using a similar method to that adopted for the high pressure compaction tests (section 4.5.1). The specimen was first trimmed with a 78 mm diameter cutting ring and then pushed into the testing ring. Two saturated filter papers were placed on the top and bottom of the sample, which was then positioned accurately on the base and clamped with the flange and studs. The top loading cap containing the larger saturated porous stone was lowered onto the sample and the annular plate with the dial gauges was positioned from the top. The spacers and the load cell were then positioned and the pedestal of the loading machine was raised to bring the assembly into contact with the head of the machine. The gear box was adjusted to give the desired rate of strain which was chosen so as to produce only a negligible pore water pressure at the base.

4.5.6 *Scanning electron microscope*

A Cambridge Stereoscan 600 was used for studying fabric. The samples were usually air dried and sample preparation techniques described by Barden (1971) were used. The sequence adopted was as follows:

(i) A 5 mm thick section perpendicular to and containing the particular surface of interest was sliced off the test specimen. A tensile fracture was effected at the point of interest and the sample containing the fresh fracture

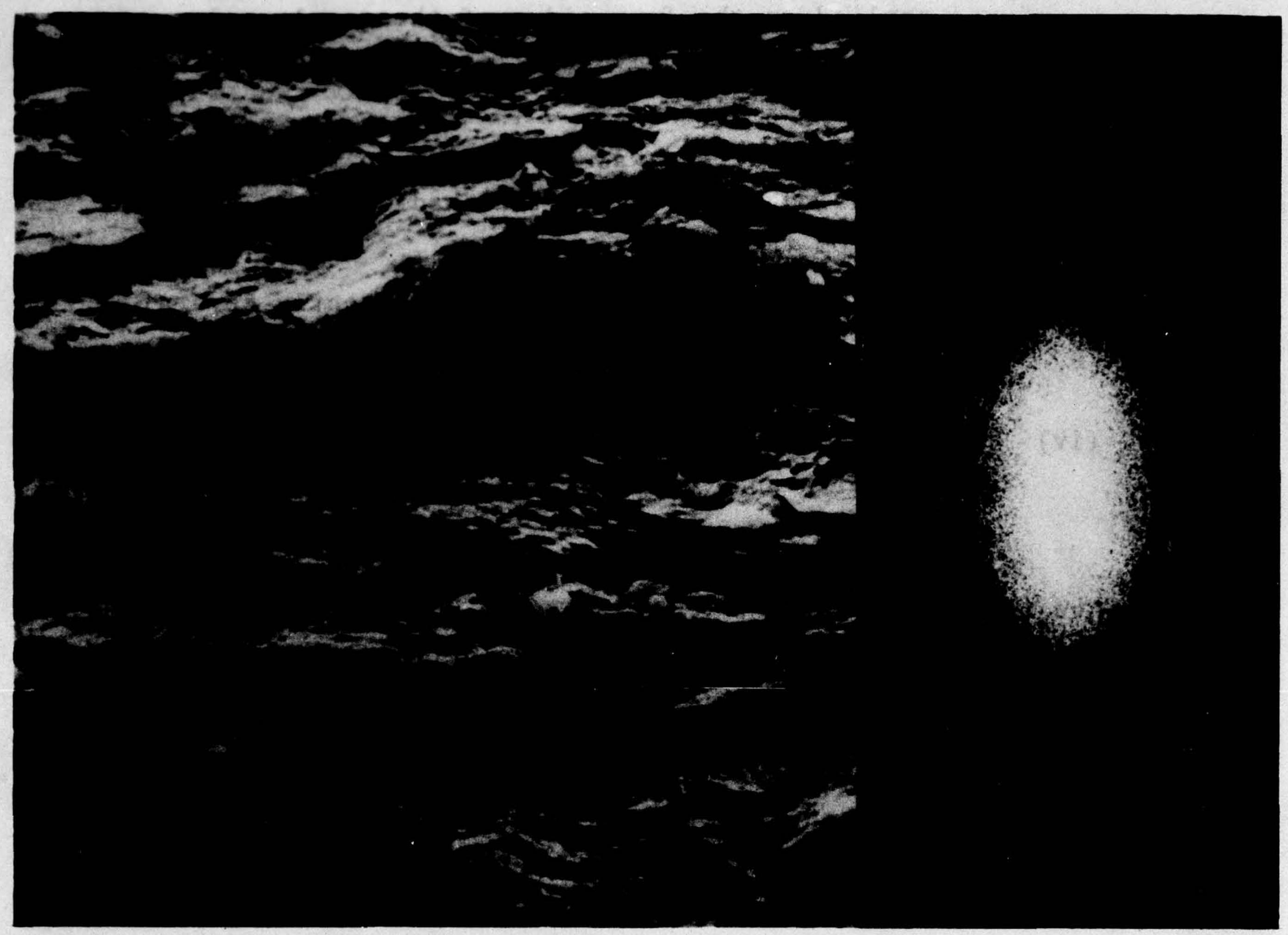


Scanning electron micrographs of the fabric produced in a sample compacted to 2,5000 psi (175 kg/cm^2) at 60 psi/hr (4.2 $kg/cm^2/hr$). Scale bar 10μ.

4.1(a) Sample from the undrained end.
4.1(b) Sample from the drained end (see over).

A Fourier analysis of the micrographs is included, which used coherent light (Fraunhoffer diffraction). The Major/Minor axial ratio of the diffraction elipse in the sample from the drained end is larger than that from the undrained end, confirming a real, rather than apparent, preferred orientation.

Plate 4.1(a)



10μ

For caption see Plate 4.1(a).

Plate 4.1(b)

surface was fixed onto an aluminium stub using adhesive (Durafix). A coating of aluminium paint was applied on the four sides of the sample and on the stub head to give a perfect electrical conducting surface.

(ii) The fracture surface was air jetted to remove all coarse dislodged particles that had remained as debris from the fracture.

(iii) The fracture surface was then peeled gently several times with an adhesive tape to remove all fine dislodged particles that still remain on the surface.

(iv) The fracture surface was then coated, under vacuum, with about 200 Å thick film of gold.

One object of the electron microscopy study was to investigate the development of preferred orientation of particles. The crude comparison of electron micrographs for the degree of preferred orientation is invariably prone to bias from the observer. An image analysing technique was therefore used to assist in the comparisons. The technique used the 2-D transform of the electron micrograph applying coherent optics (Fraunhofer diffraction). This produces a qualitative record of the image details in terms of dimensions and also enables a quantitative record to be made of the intensity pattern of the image (Nyberg et al, 1971). A parallel coherent beam of light is passed through a transparency of an SEM micrograph. Most of the micrographs in this study appeared as a set of linear features which produced diffraction patterns in the form of a 2-D distribution approximately to an ellipse. In micrographs showing very high order preferred orientation the diffraction pattern is elongated in a direction perpendicalar to the direction of particle orientation. A circular diffraction pattern is the Fourier transform of a random orientated structure (for example see Wijeyesekera & de Freitas, 1976). See Plates 4.1(a) and (b).

4.5.7 *X-ray diffraction*

X-ray diffraction analysis was used for identification of clay minerals and for quantitative determinations of

particle orientation. A Phillips PW 1060 diffractometer equipped with a linear recorder was used for this purpose. Cobalt (K_α) radiation was used with an iron filter to eliminate any β radiation and a 38 kv and 24 mA supply was chosen with a 1 kw generator to obtain high intensity and a good peak to background ratio. The Geiger counter scanned at a rate of 1°/min.

A qualitative interpretation of the XRD traces was made with the aid of standard tables Brown (1961). The technique proposed by Schultz (1964) for semi-quantitative mineralogical analysis of Pierre Shale was adopted.

In all quantitative studies the ratios of peak intensities were used so that the data would be automatically corrected for variations in crystallite concentrations.

4.5.8 *Optical microscopy*

The optical microscope with photometric attachments as developed by Tchalenko (1967) was used in this study for both qualitative and quantitative microscopy of thin sections. The thin sections were prepared by impregnating slices of the clay with Carbowax 6000. The Carbowax is completely miscible with water when liquid at 60°C and shows no birefringent effect in thin section indicating that it has not affected the clay aggregate. The sections were kept immersed in liquid carbowax for two weeks to ensure complete replacement of the pore water. The thin sections were prepared in the usual way using carborundum powder but paraffin had to be used as a grinding fluid instead of water.

The quantitative studies were made on sections cut in the plane of the maximum compressive stress. Observations were made of the intensity of light transmitted through crossed polars for different stage angles. All intensity readings were made on areas

of 0.33 mm diameter and at similar incident illuminations. The maximum and minimum values of transmitted light were recorded and the birefringent ratio and anisotropy index computed; Smart (1967).

The range of birefringence ratios obtained for any one specimen is an indication of the homogeneity of the fabric.

4.5.9 *Index tests*

Atterberg limits

The plastic and liquid limits were determined using the normal procedures described in BS 1377 (1967).

Moisture content

Moisture content determinations were made by weighing the loss in water of the samples after drying in an oven at 105°C for 24 hours.

Specific gravity

The specific gravity of the materials used for testing was measured using density bottles by the method described in BS 1377 (1967).

Particle size distribution

The particle size distributions of the natural materials used for testing were determined in the standard way using the methods described in BS 1377 (1967). Pre-treatment was required for some samples in order to disaggregate the clay minerals.

4.5.10 *Strength tests*

Falling cone penetrometer

The shear strength of the specimens after consolidation were determined using a laboratory cone penetration apparatus similar to that described by Hasslo (1957). A cone of a certain weight and apex angle is suspended vertically over and just touching the surface of the clay sample. When the cone is released it penetrates into the sample. The depths of penetration gives a measure of the undrained shear strength of the clay.

The small size of the penetrometer enabled a large number of determinations to be made on each specimen from which a distribution of shear strength through the specimen could be examined.

Standard shear box

A standard shear box machine was used to obtain values of shear strength in samples 50 mm square and approximately 25 mm thick. A cutter and extruder were used to trim the sample and the box was then assembled by placing the grooved lower platen into the split shear box followed by one of the porous plates, the sample, the other porous plate and finally the top platen. The shear box was then placed into the carriage and the normal load applied via a weight hanger. After consolidation had taken place, the sample was sheared at a predetermined rate and the shear strength monitored with a proving ring.

Small shear box

In order to test several samples cut from a specimen taken from the high pressure cell, a special shear box was designed and constructed. This is capable of shearing samples 20 mm square and 12 mm thick. The small shear box is compatible with the rig used for the standard box and the testing procedure adopted is identical; see Fig. 3.6.

4.5.11 *Chemical tests*

Cation exchange capacity

The cation exchange capacity was determined from the adsorption of a basic dye by the silicate clay minerals; Faust (1940). Methylene blue is adsorbed irreversibly from a dye solution with an equivalent release of exchangeable cations and has been used successfully; Robertson and Plesch (1948); Robertson and Ward (1951).

A 0.005 N methylene blue solution was titrated against aliquots of a dilute clay suspension. The course of the titration to the end point was followed by periodically spotting a drop of the titrated slurry

on filter paper, the end point being indicated when excess dye appeared as a sky blue colouration radiating from the darker dyed solids in the centre.

4.6 Pore fluid testing

The pore fluids expelled during compaction were analysed as a single batch for each high pressure test so that if any reagent or instrumental errors were present they would apply equally to all the samples. The analyses were carried out using de-ionised, distilled water (DI water) and commercial analytical reagent quality chemicals. A special set of glassware was kept solely for the analysis of these pore fluids in order to prevent contamination from other highly concentrated solutions.

The methods used for the analysis of potassium, sodium, calcium, magnesium, sulphate, chloride and dissolved solids concentrations are given below. The cations were analysed using a spectrophotometer and the anions by using a nephelometer. Comparisons of sample behaviour with that of standard solutions of known concentration was used as a basis for these analyses.

4.6.1 *Analysis of cations using a spectrophotometer*

The instrument used for the analysis of the cations was a Pye Unicam SP 90 spectrophotometer. The sample was accepted by the spectrophotometer in the form of a solution in which the elements to be determined have a concentration of 1 to 100 mg/l. This was achieved by preparing a solution of the pore fluid by taking 2 ml of the original fluid, diluting with 5 ml of 2 N hydrochloric acid and bringing the volume up to the required dilution with DI water.

The sample was introduced into a flame in the form of small droplets. Much of the sample becomes dissociated at the flame temperature into the atomic state and a small proportion of these atoms are then

excited to higher energy levels. The decay of excited atoms causes radiation of light, characteristic of the element concerned, and this light is used in analysis by flame emission spectroscopy. The majority of the atoms in the flame remain in the ground state energy level and these are the atoms which are measured in atomic absorption spectroscopy.

A hollow cathode lamp, whose cathode incorporates the element being determined, produces light with a line spectrum characteristic of that element. The light is passed through the flame and undergoes some absorption by the ground state atoms of the same element in the flame. By comparing the intensity of this light after it has passed through the flame before and after the introduction of the sample, the instrument indicates the amount of light absorbed which is a measure of the concentration of that element in the sample.

Potassium

The diluted pore fluid samples were compared with a series of standard solutions containing 1.0, 2.0, 3.0, 4.0 and 5.0 mg/1.of potassium ions. The apparent potassium concentrations were then reduced by a correction factor to allow for the enhancement of potassium by sodium.

Sodium

The diluted samples were compared with a series of standard solutions containing 1.0, 2.0, 3.0, 4.0 and 5.0 mg/1 of sodium ions.

Magnesium

The diluted pore fluid samples were compared with a series of standard solutions containing 0.3, 0.6, 1.5, 3.0 and 4.5 mg/1 of magnesium ions.

Calcium

The diluted samples were compared with a series of standard solutions containing 2, 5, 10, 15 and 20 mg/1 of calcium ions.

4.6.2. *Analysis of anions using a nephelometer*

The conventional quantitative chemical analysis technique based on titrations could not be used because of the very low concentrations of the anions. However, the concentrations were sufficiently low for the reagents normally used in titrations to form a colloidal suspension rather than a precipitate. The optical density of this colloidal suspension is proportional to the anion concentration and provided a standard preparation procedure is followed, the concentration of a sample can be obtained by comparison with a series of standard solutions. A suitable method for measuring the optical density is to measure the scatter of a light beam in the suspension with a nepholometer.

The pore fluid samples were prepared by transferring 1.0 ml of the sample to a test tube and adding 4.0 ml of glycerol solution (1 volume glycerol dissolved in 2 volumes ethanol) in order to increase the viscosity of the solution. 2 ml of sodium chloride solution (240 g NaCl in 600 ml water with 20 ml concentrated HCl) were also added in the case of the sulphate solutions. The solution was then mixed and diluted to 20 ml using DI water and remixed. For each sulphate determination 60 mg of barium sulphate (crystal size between -20 and +30 mesh) was prepared and for the chloride determination 60 mg of silver nitrate was prepared. The 60 mg of salt was then added to the diluted solution, a stopper inserted in the test tube, and the tube shaken for 1 minute by inversion once every second. During this time the salt crystals dissolve. The tube is then allowed to stand for two minutes for the turbidity to develop. A standard volume of the solution was then taken and poured into a carefully cleaned glass tube of uniform optical density which was then placed in the nephelometer. The turbidity was compared with the calibration series and hence the concentration was obtained.

Sulphate

The diluted pore fluid samples were compared with a series of standard solutions containing 0, 10, 20, 30, 40, 50 and 100 mg/l of sulphate ions.

Chloride

The diluted samples were compared with a series of standard solutions containing 0, 0.42, 0.85, 1.27 and 1.70 mg/l of chloride ions.

4.6.3 *Analysis of dissolved solids*

The concentration of dissolved solid in the original pore fluid was obtained by drying a 2 ml portion of the fluid at 105°C and determining the loss in weight due to the evaporation of the water.

4.6.4 *Analysis of anions using titration methods*

Chloride (Mohr's method)

The chloride solution is titrated with standard silver nitrate solution in the presence of potassium chromate. The silver nitrate reacts with the chloride and insoluble silver chloride is precipitated. When all the chloride has been precipitated the excess silver nitrate reacts with the chromate to form reddish-brown silver chromate. 0.2 ml id dducted from the titre to allow for the solubility of silver chromate.

1 ml of potassium chromate indicator is added to the sample and titrated with $\frac{N}{35.5}$ silver nitrate. The solution can be standardised against a sodium chloride solution of known concentration.

5. FIELDWORK

5.1 Purpose of fieldwork

Fieldwork has been carried out in order to obtain samples for laboratory testing. The locations visited have been selected because of their known conditions of exposure and the suitability of the material for testing. The BC series of tests were in part conducted on undisturbed specimens of kaolinitic clay collected in south-west England. Normally consolidated clays were obtained from the intertidal flats of the Falmouth Estuary, Cornwall, and over-consolidated clays of Oligocene age were sampled from the open clay pits of South Devon. A brief investigation was made of the diagenesis of fine grained calcareous sediments and the Cretaceous chalk was examined in three localities in south-east England. The particular sites are listed in Table 5.1.

5.2 Product of field work

5.2.1 *Recent sediments from Falmouth Estuary*

The recent sediments from the Falmouth Estuary in Cornwall were known to be of relatively simple mineralogy. A study was made of the estuary and a series of 38 mm core samples collected to select a convenient and suitable site for the main sampling. A block sample of the clay was then collected and coated with foil to preserve its natural water content. A piston sampler (Fig. 3.1) was also developed to extract field samples for direct testing in the high pressure equipment. The 100 mm diameter samples were collected in PTFE sleeves to avoid contamination and facilitate subsequent assembly in the high pressure equipment. The body of the sampler is pushed into the sediment relative to the piston during the sampling process. A thick aluminium base on which the piston is supported aids in distributing the weight of the operator during sampling.

5.2.2 *Ball Clays from Devon*

The Bovey ball clays are an overconsolidated fluvio-lacustrine deposit. Some of their geotechnical and sedimentary properties have been described by Best and

TABLE 5.1

Samples collected from fieldwork. All localities are in England.

Location	Lat : Long.	Nature of samples collected
Eastbourne, Sussex	50°44'30"N:0°14'30"E	(Site visit only)
Radlett, Herts	51°41'40"N:0°20'35"W	Chalk (Upper Chalk, Cretaceous)
Dunstable, Beds	51°52'45"N:0°32'20"W	Chalk (Upper Chalk, Cretaceous)
Falmouth, Cornwall	50°13'15"N:4°57'15"W	Estuarine Clay (Recent)
Meeth Pit, Devon	50°51'20"N:4°04'40"W	Ball Clay (Oligocene)

250 x 250 x 200 mm were cut from a freshly exposed beach at Meeth pit in the Petrockstow basin. The samples were trimmed to fit snugly into a metal tin which could be sealed to prevent loss of moisture.

5.2.3 *Chalk in south-east England*

Three short field trips were made to study natural chalk exposures. One was to Eastbourne, Sussex, to examine structures in the chalk exposed by coastal erosion and the other two were to collect samples of the Upper Chalk for subsequent testing. The two sampling sites were at Radlett, Herts and Dunstable, Beds. The samples were collected in tin boxes sealed with polythene to prevent subsequent dehydration.

6. LABORATORY WORK

6.1 Programme of work with high pressure equipment

The initial tests used different rates of pressure rise and fall and investigated their influence on the consolidation behaviour of remoulded kaolinitic ball clay. There then followed a series of tests that studied the influence of pore fluid chemistry, varying from fresh to hypersaline water on the same clay at the same loading rates.

The testing programme on kaolinitic clay was completed by an examination of the consolidation behaviour of natural kaolinitic deposits using material collected from the south-west of England: this enabled a comparison to be made between the consolidation and associated changes in chemistry and fabric of remoulded and undisturbed samples of kaolinitic materials.

The next stage of high pressure testing concerned the compaction of montmorillonite. The programme of tests involved montmorillonite remoulded in distilled water of saline water and then compacted at a constant rate of 10 psi/hr followed by unloading at 20 psi/hr. The tests were carried out at constant temperatures ranging from 20 to 80°C.

A summary of all thes high pressure tests that have been conducted during the period of this research contract is presented in Table 6.1.

6.2 Programme of work with other equipment

Comparison of the high pressure tests on ball clay carried out at a constant rate of change of stress with similar tests carried out at a constant rate of strain were made using constant rate of strain apparatus (see chapter 3). Investigations at low stress levels were made to observe the effects of changes in temperature on consolidation of kaolinitic materials.

TABLE 6.1

Summary of tests in the high pressure, high temperature oedometer

Sample	Date	Max Pressure	Max Temperature	Time	Material
BC.CHP.12	15.2.73	2500 psi	17°C	7 days	Ball clay remoulded in distilled water
BC.CHP.13	8.3.75	418	17	5	"
BC.CHP.14	14.3.73	4653	17	11	"
BC.CHP.15	22.5.73	7000	17	4	Ball clay remoulded in half saline water
BC.CHP.17	2.7.73	5520	17	8	"
BC.CHP.18	5.10.73	5015	17	8	Ball clay remoulded in distilled water
BC.CHP.19	26.10.73	6504	17	16	"
BC.CHP.20	15.12.73	6800	17	16	Ball clay remoulded in hyper-saline water
BC.CHP.21	27.12.73	8000	17	10	"
BC.CHP.22	7.3.75	10	17	20	Ball clay sedimented in distilled water
N.BC.CHP.1	25.6.74	7800	17	1	Ball clay undisturbed
N.FA.CHP.1	10.9.74	4300	17	14	Falmouth clay undisturbed
FB1	18.11.74	10	17	6	Fuller's earth remoulded in distilled water
FB1a	29.11.74	3300	17	9	"

TABLE 6.1 continued

Sample	Date	Max Pressure	Max Temperature	Time	Material
FE7	11.3.75	5000	40	43	Fuller's earth sedimented in distilled water
FE11	24.4.75	5000	60	37	"
FE12	7.7.75	280	80	10	"
FE13	18.7.75	5000	80	40	"
FE22	31.10.75	320	20	6	"
FE16	27.8.75	5710	40	51	Fuller's earth sedimented in saline water
FE24	14.11.75	5175	60	34	"
FE27	9.1.76	1620	20	13	"
FE29	22.1.76	4500	20	36	"
FE30	26.3.76	5000	60	35	"
FE32	Test in progress		80		"

See Supplementary Report: August to December 1976, Chapter 10.

TABLE 6.1

Further investigations into the basic consolidation behaviour of materials at low stress levels has been concerned with the effects of moisture content and temperature. The effects of temperature were examined for remoulded Chalk (C series) and remoulded Fuller's Earth (FE series), and moisture content for remoulded Fuller's Earth (FE series). A variation in moisture content, by the addition of varying amounts of chalk or sand filler, and the consequence of this on the consolidation characteristics were examined for Fuller's Earth remoulded with Chalk (CF series) and with Sand (S series).

The most recent consolidation testing has used the Rowe Cell. This Cell has been adapted to enable consolidation to be carried out at elevated temperatures and for pore fluids to be substituted. These tests are designed to provide information on the compaction characteristics of sediments similar to those being tested in the high pressure equipment but over a lower range of pressures (0-125 psi) and temperatures (15-30°C).

A summary of the tests carried out other than in the high pressure apparatus is presented in Table 6.2.

TABLE 6.2

Summary of consolidation tests other than those carried out in the high pressure, high temperature oedometer

(All are oedometer tests unless otherwise indicated CRS = constant rate of strain test; R = Rowe Cell test)

Sample	Date	Max Pressure	Max Temp	Material
RT 1	22.7.73	140 psi	17°C	Ball clay
T 1			50	"
RT 2	4.9.73	140	17	"
T 2			58	"
RT 3	29.9.73	140	17	"
T 3			49	"
RT 4	14.10.73	140	17	"
T 4			70	"
BC.CRS.1	4.1.74	2830	17	CRS; ball clay
BC.CRS.2	21.1.74	814	17	"
BC.CRS.3	13.2.74	5	17	"
BC.CRS.4	1.3.74	3450	17	"
C 1	10.5.75	70	17	Chalk remoulded in distilled water
C 2	20.5.75	70	30	"
C 3	2.6.75	70	40	"
C 4	22.6.75	70	50	"
C 5	16.7.75	70	60	"
C 6	11.8.75	70	40	"
C 7	27.8.75	70	20	"
CF 1	10.5.75	70	17	100:0 Chalk: Fuller's Earth
CF 2	20.5.75	70	17	90:10 "
CF 3	2.6.75	70	17	80:20 "
CF 4	22.6.75	70	17	70:30 "
CF 5	16.7.75	70	17	60:40 "
FE 2	19.11.74	35	15 40	Fuller's Earth remoulded in distilled water

Sample	Date	Max Pressure	Max Temp	Material
FE 3	27.11.74	70	{15 40	Fuller's Earth remoulded in distilled water
FE 4	30.12.74	3	{15 40	"
FE 4a	6.1.75	70	{15 40	"
FE 5	19.1.75	70	{15 30	"
FE 6	14.2.75	70	{15 15	"
FE 8	11.3.75	70	{15 50	"
FE 9	31.3.75	70	60	"
FE 10	21.4.75	70	70	"
FE 14	30.7.75	70	20	Fuller's Earth remoulded in saline water
FE 15	30.7.75	70	17	Fuller's Earth remoulded in distilled water
FE 17	11.8.75	70	17	"
FE 18	27.8.75	70	17	"
FE 19	8.9.75	70	20	"
FE 20	8.9.75	70	17	"
FE 21	20.10.75	70	40	"
FE 23	20.10.75	70	17	"
S 1	2.6.75	113	17	50:50 Fuller's Earth: sand
S 2	2.6.75	113	17	70:30 "
S 3	23.6.75	113	17	30:70 "
S 4	23.6.75	113	17	90:10 "
S 5	16.7.75	113	17	80:20 "
S 6	16.7.75	113	17	60:40 "

TABLE 6.2 continued ...

Sample	Date	Max Pressure	Max Temp	Material
S 7	31.7.75	113	17	40:60 Fuller's Earth: sand
S 8	31.7.75	113	17	100:0 "
S 9	14.8.75	113	17	50:50 "
S 10	14.8.75	113	17	70:30 "
FE 25	28.11.75	60	17	R; Fuller's Earth remoulded in distilled water
FE 26	11.11.75	50	60	"
FE 28	22.3.76	30	30	"
FE 31			20	R; Fuller's Earth remoulded in saline water with substitution of distilled water
FE 33	12.5.76	Test in progress	40	"

See Supplementary Report: August to December 1976, Chapter 10.

TABLE 6.2

AD-A046 946 IMPERIAL COLL OF SCIENCE AND TECHNOLOGY LONDON (ENGLAND) F/G 8/13
ARTIFICIALLY SIMULATING THE GEOLOGICAL HISTORY OF CLAY.(U)
JUL 76 J L KNILL, B A CLARK, M H DEFREITAS DA-ERO-124-74-G-0085

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7. RESULTS*

7.1 Results of High Pressure Work

The results of the high pressure work carried out during the period of this grant are given on the following pages. They fall into three basic groups as follows

FE series. Tests FE 1, 1a, 7, 11, 12, 13, 16, 22, 24, 27, 29, 30.

BC CHP series. Tests BC CHP 12, 14, 15, 17, 18, 19, 20.

N series. Tests N BC CHP 1, N FA BC CHP 2.

For each test is listed the material used, the loading cycle and variations during compaction of axial pressure, pore fluid pressure, thickness, void ratio, permeability(1) and coefficient of volume decrease. The results of the chemical analysis of the pore fluids expelled during compaction are given in tabular form. The Tables for the chemistry of pore fluids expelled from the Ball Clays (BC CHP series and N series) have been compiled from graphs . For each of these tests each element was analysed 4 to 5 times and a trend line drawn. The values given in the Tables describe these lines.

The following tests, although commenced and listed in Chapter 6, were abandoned for various reasons. In each case the results are either non-existent or limited:

FE 1 (repeated as FE 1a).
FE 12 (repeated as FE 13).
BC CHP Tests 1 to 11: these were run at the time the equipment was being developed and were used mainly for testing the equipment rather than the material.
BC CHP 13 (repeated as BC CHP 14).
BC CHP 16 (repeated as BC CHP 17).
BC CHP 22

7.2 Results of Low Pressure Work

The results of the low pressure work carried out in oedometers and constant rate of strain apparatus during the period of this grant are given on the following pages. They fall into six basic groups as follows.

* FOOTNOTE: See Supplementary Report .... Chapter 10.

BC CRS series. Tests BC CRS 1, 2, 3, 4.

C series. Tests C1, 2, 3, 4, 5, 6, 7.

CF series. Tests CF 1, 2, 3, 4, 5.

FE series. Tests FE 3, 4a, 5, 6, 8, 9, 10, 14, 15, 17, 18, 19, 20, 21, 23.

S series. Tests S 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.

The following tests although listed in Chapter 6 have no results reported:

FE 2 (abandoned and repeated as FE 3)

FE 4 (abandoned and repeated as FE 4a).

FE 25, 26, 28, 31 (data not analysed to date).

For each the change in void ratio with pressure is given together with the properties of the material compacted. Data relating to the chemistry of the pore fluids expelled from FE 25 is also presented.

7.3 Results of Consolidation Tests with Substitution

The pore fluid substitution system is still not fully designed and the substitution tests in the Rowe Cell have only just commenced. The chemical analysis of the expelled pore fluids had not been carried out at the time of the preparation of this report but the tests carried out so far are listed in Table 6.2 in section 6.2.

7.4 Unloading

The effects of unloading on the behaviour of clay specimens after compaction are detailed on the figures in sections 7.1 and 7.2 relating to tests in the high and low pressure oedometers. Unloading always produced a swelling of the specimen, e.g. in FE 24.

The total volume change of the specimen during unloading is much less than during burial even though water was available for the specimen to take up.

7.5 Results of small shear box tests

Small shear box tests have been carried out on the products of high pressure tests FE 1a, 7, 11, 12, 13 and 22. For each specimen from these tests six samples were cut for the shear box, three from the drained end and three from the undrained end. The samples from each end

were then sheared at a constant rate under different normal loads and the shear stress and strain recorded. The shear strength parameters obtained from these tests are summarised below:

Test	Maximum Compaction Pressure psi	Drained end				Undrained end			
		Peak		Residual		Peak		Residual	
		C kN/m^2	ϕ	C kN/m^2	ϕ	C kN/m^2	ϕ	C kN/m^2	ϕ
FE 1a	3500	625	46^o	160	4^o	530	46^o	18	30^o
FE 7	5000	520	36	132	6½	520	36	132	6½
FE 11	5000	650	43	70	31	650	30	70	15
FE 12	280	180	10	75	10	157	11	48	7½
FE 13	5000	700	28	115	20	395	28	100	17
FE 22	320	60	10½	45	12	20	12	42	9

Note: Although drainage was allowed during shearing, the shear strain rate of 0.1 mm/min was probably insufficient to enable total dissipation of excess pore pressures owing to the extremely low permeability of montmorillonite. For this reason the shear strength parameters quoted above are probably closer to the undrained strengths.

The programme of shear box testing is continuing to provide information on the repeatability of these shear test results and the strength of the remaining specimens.

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(1) Note on presentation of permeability values:- The graphs for BC CHP tests show the spread of calculated values for permeability as derived from using in each calculation one of the following assumptions

(a) input data corrected for C_v

(b) input data uncorrected for C_v

(c) input data assumes linear variation of pore water pressure with axial load

TEST NO. FE 1 **Date: 18.11.74**

DETAILS OF TEST MATERIAL

Fuller's earth remoulded in distilled water

TYPE OF TEST

Rate of loading; 10 psi/hr

Rate of unloading; 20 psi/hr

Salinity of initial pore fluid; non saline

Maximum consolidation pressure 10 psi

PROPOSED INVESTIGATION

Compaction of Ca^{-} montmorillonite at 17°C

INITIAL CONDITION OF SAMPLE

Thickness; 5.325 inches

Air dry weight; 1756.0 g

FINAL CONDITION OF SAMPLE

Moisture content; 109.1%

Thickness; 3.750 inches

Weight; 1103.0 g

FURTHER COMMENTS

During preconsolidation at a rate of 0.001 inch/min high pore pressures developed. The rate of loading was subsequently reduced to 0.00013 inch/min. After preconsolidation the sample was observed to have unequal strength throughout its length as a consequence of the high rate of preconsolidation and so the test was abandoned.

TEST NO. FE 1a **Date 29.11.74**

DETAILS OF TEST MATERIAL

Fuller's earth remoulded in distilled water and allowed to soak for 3 days.

TYPE OF TEST

Rate of loading; 10 psi/hr

Rate of unloading; 10 psi/hr

Salinity of initial pore fluid; non saline

Maximum consolidation pressure;3300 psi

PROPOSED INVESTIGATION

Compaction of Ca^{+} montmorillonite at $17^{\circ}C$

INITIAL CONDITION OF SAMPLE

Thickness; 2.925 inches

Air dry weight; 695.2 g

FINAL CONDITION OF SAMPLE

Moisture content; 24 per cent

Thickness; 1.220 inch

FURTHER COMMENTS

Unloading had to be commenced before proposed maximum pressure of 5000 psi was attained due to limit of travel in cell.

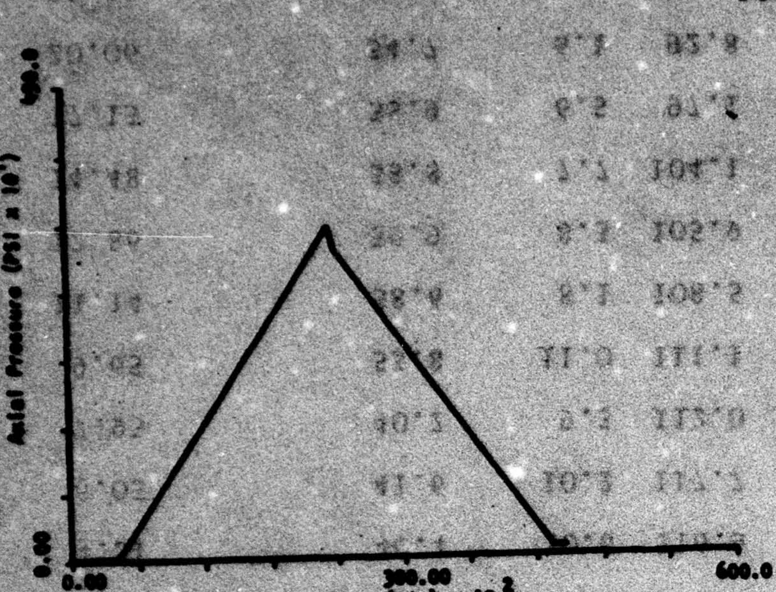
TABLE 7.1

Results of chemical analysis of pore fluids expelled from FE 1a

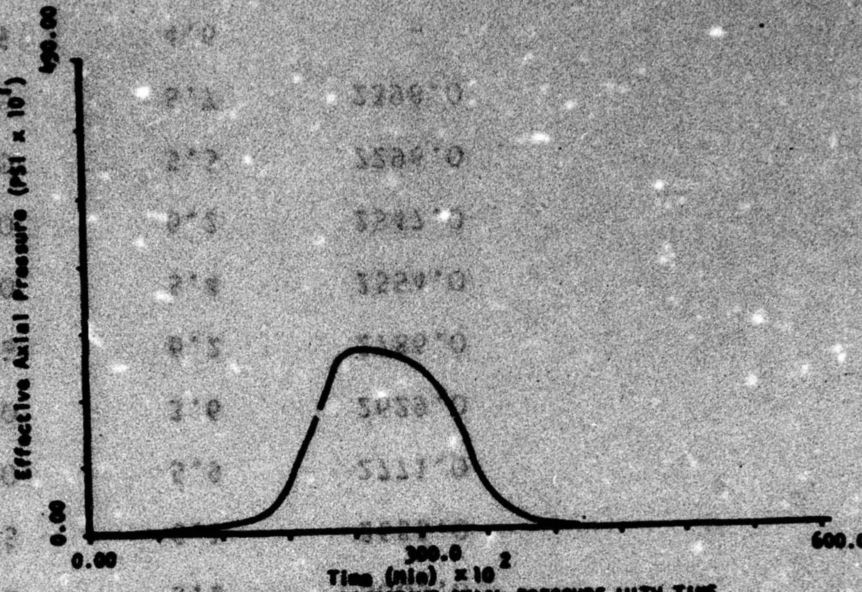
Concentration mg/l

Axial Pressure MN/m^2	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
0.86	41.8	11.2	120.2	7.1	518.0	3.9	3160.0
2.07	40.4	11.0	120.2	6.5	504.0	5.5	3096.0
2.93	40.4	10.8	118.6	6.4	521.5	3.2	3009.0
4.31	40.4	10.6	116.9	6.5	528.5	6.1	2655.0
6.03	41.6	10.2	117.7	7.2	518.0	5.9	2771.0
7.93	40.2	9.3	112.0	7.2	497.0	3.6	2629.0
9.65	53.8	11.0	111.1	7.5	472.5	6.2	2786.0
11.14	38.6	8.1	108.5	7.8	455.0	5.4	2554.0
12.86	39.9	8.3	105.9	7.9	434.0	6.2	2547.0
14.48	38.8	7.7	104.1	7.4	399.0	5.3	2296.0
17.13	35.9	6.5	97.1	7.9	371.0	5.7	2398.0
20.06	34.7	6.1	92.8	7.1	353.5	4.6	-
21.89	53.2	7.1	88.8	9.9	353.5	9.0	2850.0

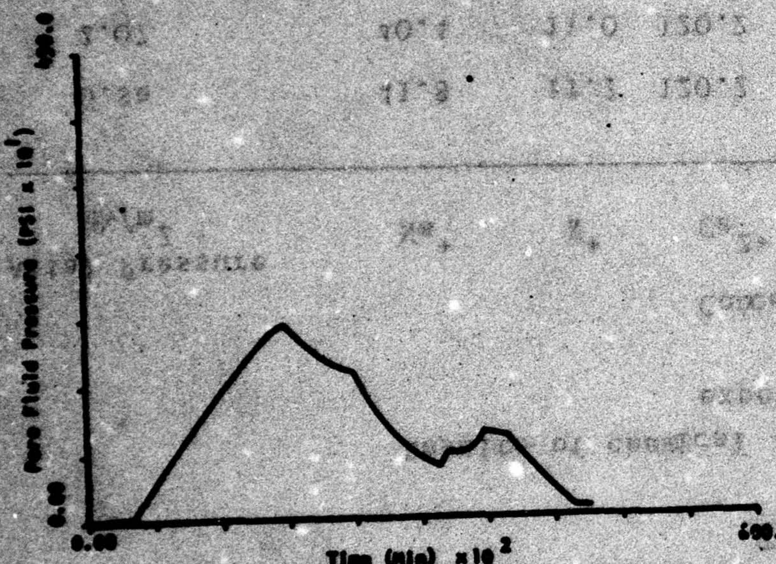
Test FE 1a



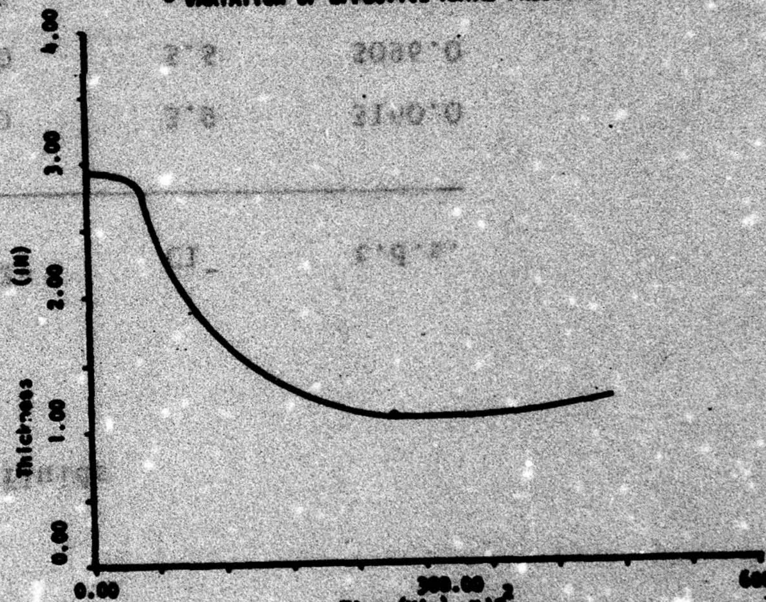
- VARIATION OF AXIAL PRESSURE WITH TIME



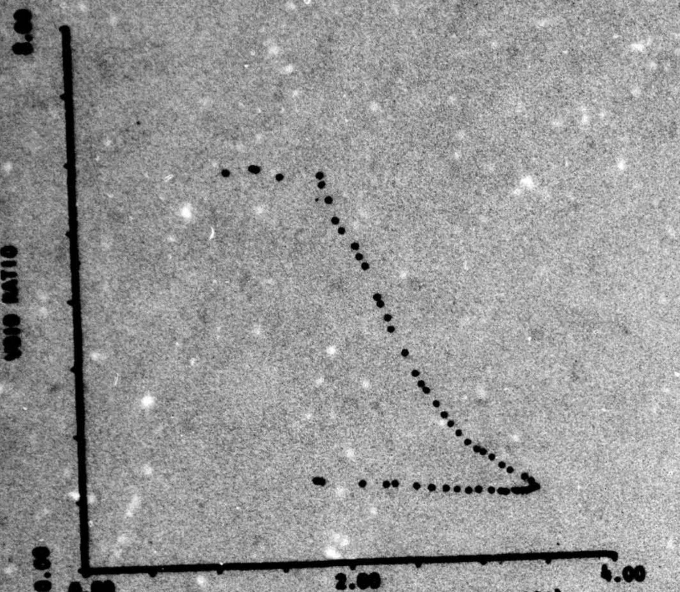
- VARIATION OF EFFECTIVE AXIAL PRESSURE WITH TIME



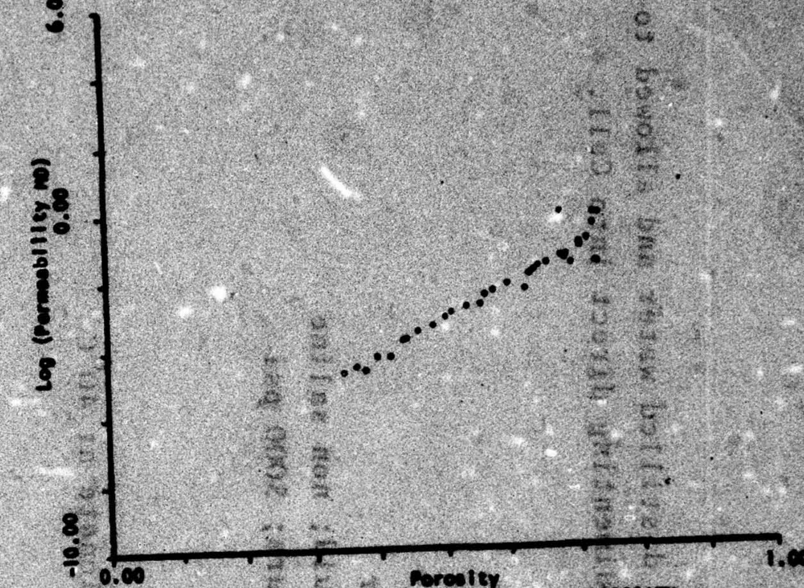
- VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME



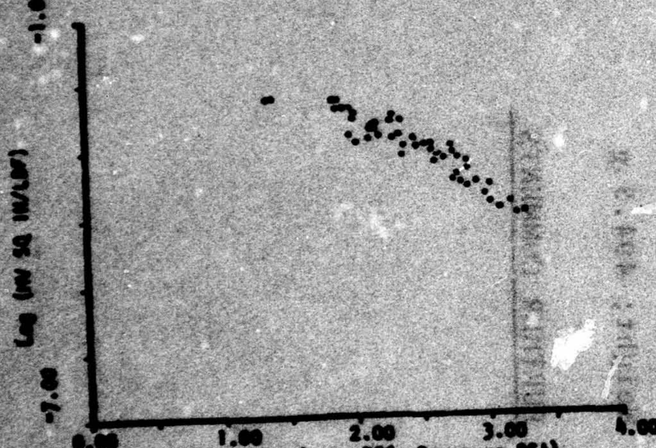
- CHANGE IN THICKNESS OF THE SAMPLE WITH TIME



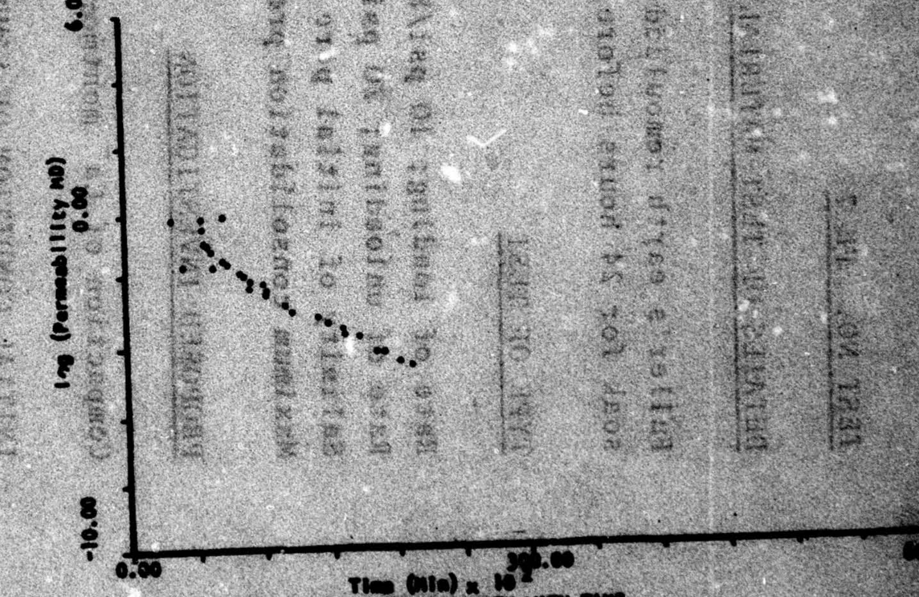
VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE



- VARIATION OF PERMEABILITY WITH POROSITY



- VARIATION OF COEFF. OF VOLUME DECREASE
WITH EFFECTIVE PRESSURE



- VARIATION OF PERMEABILITY WITH TIME

TEST NO. FE 7 Date: 11.3.75

DETAILS OF TEST MATERIAL

Fuller's earth remoulded in distilled water and allowed to soak for 24 hours before sedimenting direct into Cell.

TYPE OF TEST

Rate of loading; 10 psi/hr
Rate of unloading; 20 psi/hr
Salinity of initial pore fluid; non saline
Maximum consolidation pressure; 5000 psi

PROPOSED INVESTIGATION

Compaction of Ca^{-} montmorillonote at $40^{o}C$

INITIAL CONDITION OF SAMPLE

Thickness; 3.016 inches
Air dry weight; 498.5 g

FINAL CONDITION OF SAMPLE

Moisture content; 36.6 per cent
Thickness; 1.372 inch
Weight; 494.5 g

FURTHER COMMENTS

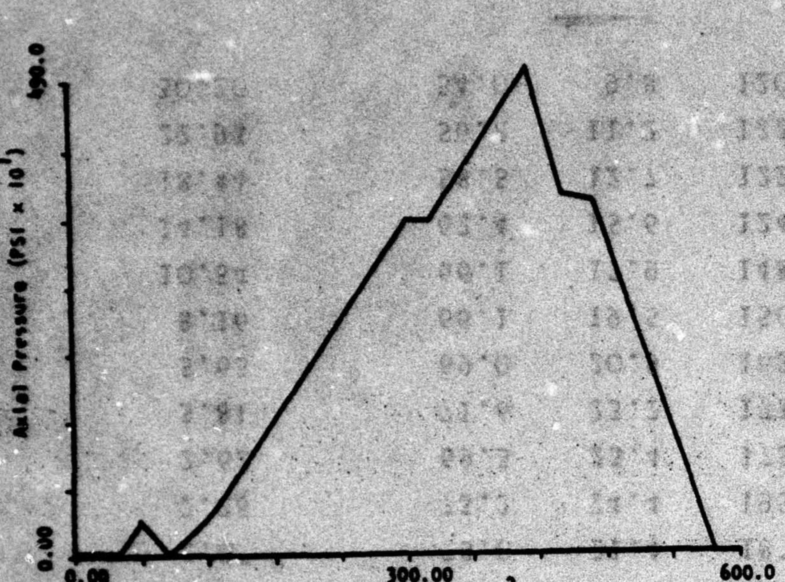
TABLE 7.2

Results of chemical analysis of pore fluids expelled from FE 7

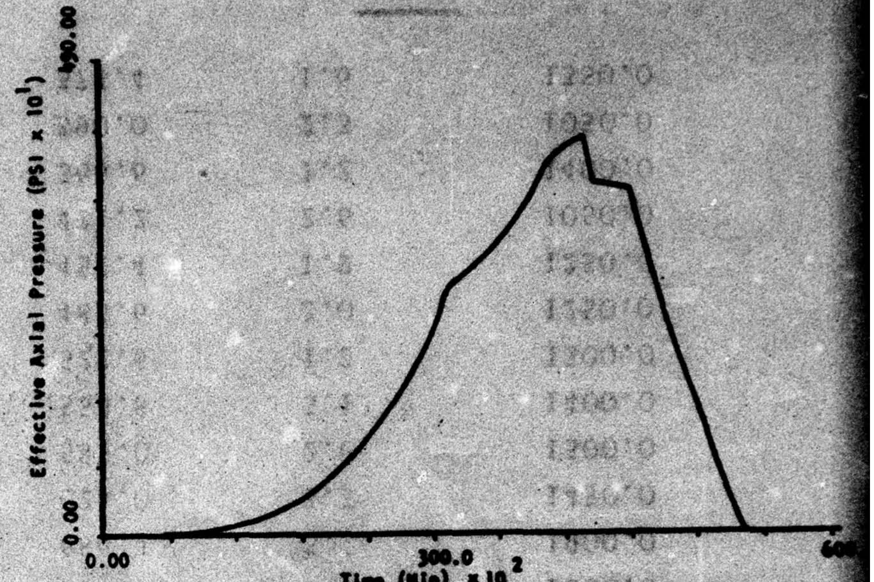
Concentration mg/l

Axial Pressure MN/m^2	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
0.07	104.1	43.9	263.2	15.6	1060.8	3.3	2550.0
0.14	84.9	32.2	255.4	11.9	920.4	4.4	2500.0
0.39	82.9	31.2	239.8	11.3	858.0	3.4	2050.0
1.14	81.4	28.3	216.4	11.2	733.2	2.3	1850.0
2.07	78.0	21.4	187.2	10.4	686.4	3.7	1900.0
2.28	73.2	24.4	195.0	9.6	624.0	3.3	1450.0
2.62	69.3	23.4	175.5	8.8	585.0	2.0	1500.0
3.81	71.6	23.2	173.6	8.4	553.8	3.1	1400.0
5.65	69.0	20.9	165.8	8.0	522.6	1.2	1300.0
8.16	66.1	19.5	150.2	7.6	483.6	2.0	1250.0
10.54	66.1	17.9	148.2	7.2	452.4	1.9	1250.0
14.18	62.4	15.6	124.8	7.2	421.2	2.6	1050.0
18.44	58.5	12.7	122.8	7.2	366.6	1.2	1400.0
22.93	56.2	11.2	122.8	7.6	390.0	2.3	1050.0
30.20	54.0	9.8	120.9	7.6	374.4	1.6	1350.0

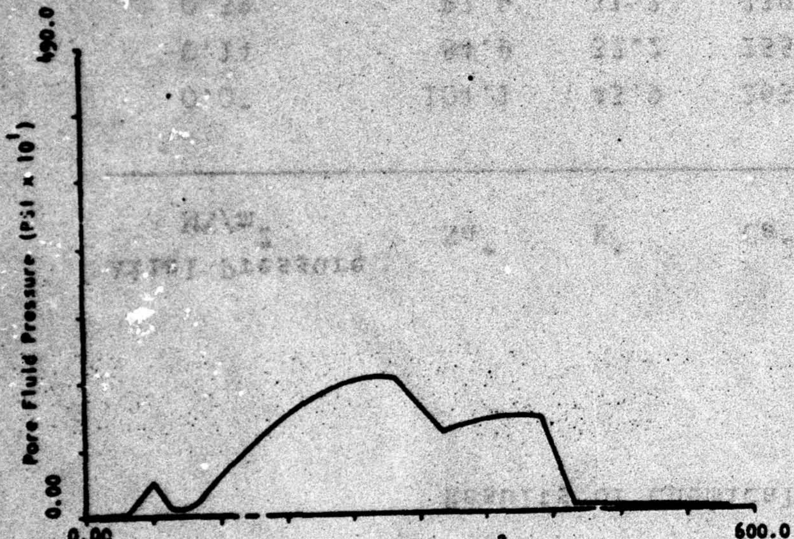
Test FE 7



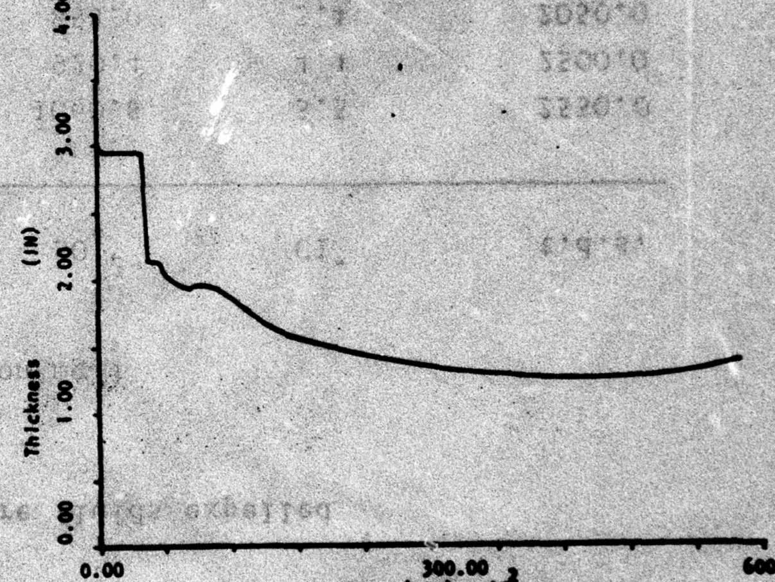
- VARIATION OF AXIAL PRESSURE WITH TIME



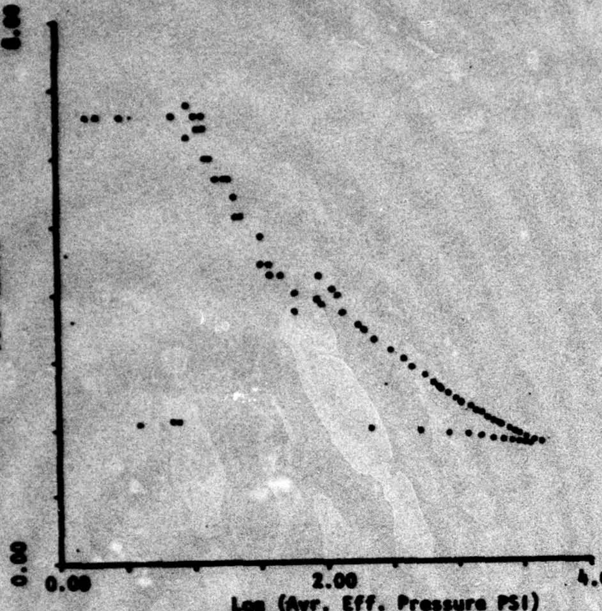
- VARIATION OF EFFECTIVE AXIAL PRESSURE WITH TIME



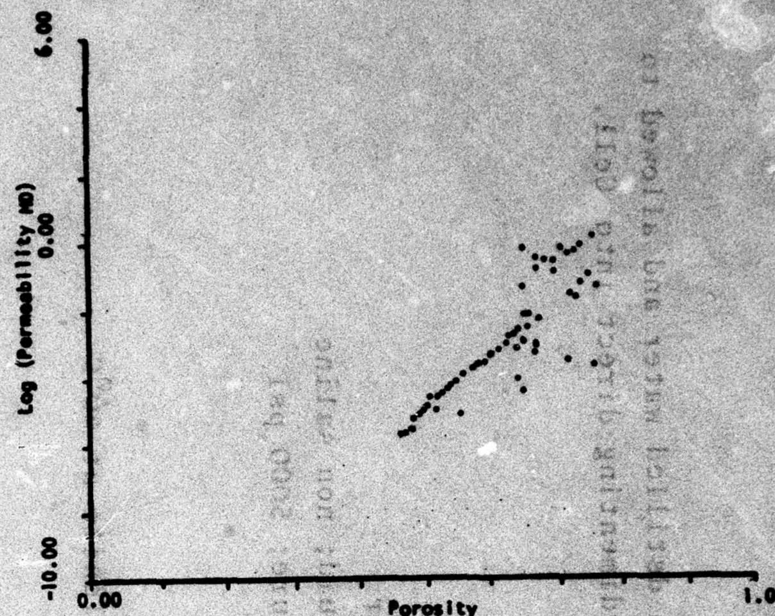
- VARIATION OF PORE FLUID PRESSUFE AT UNDRAINED END WITH TIME



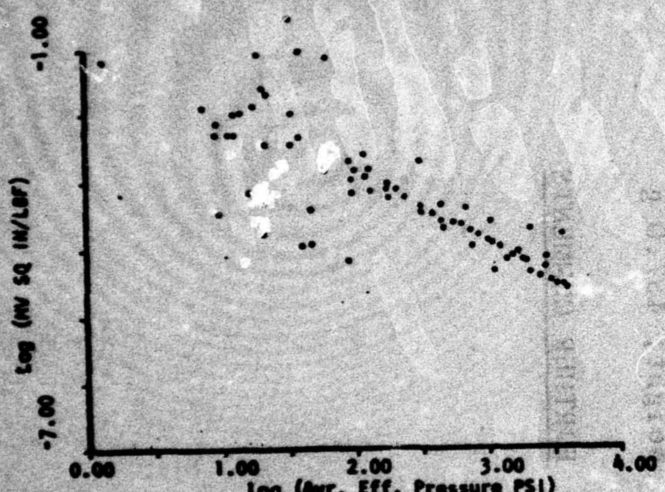
- CHANGE IN THICKNESS OF THE SAMPLE WITH TIME



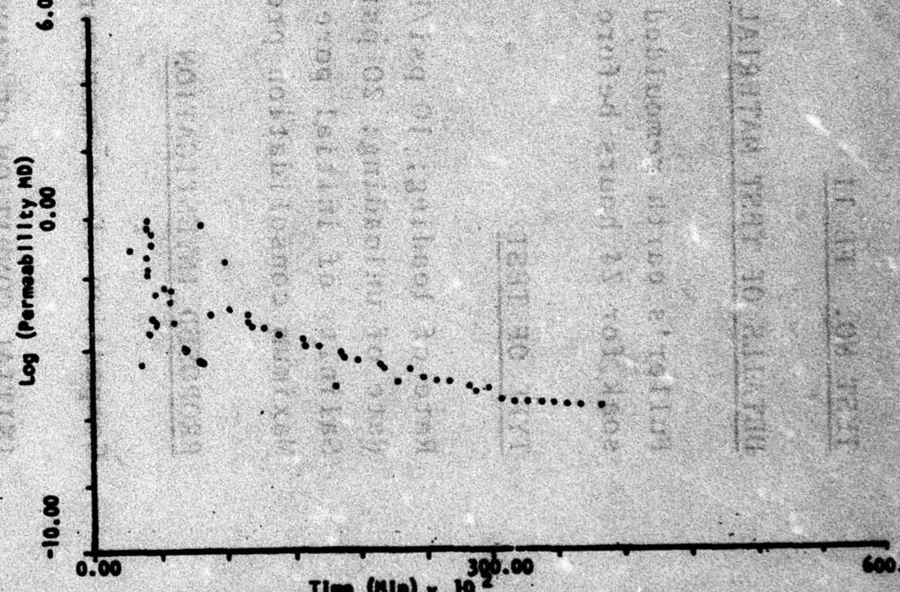
VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE



- VARIATION OF PERMEABILITY WITH POROSITY



- VARIATION OF COEFF. OF VOLUME DECREASE
WITH EFFECTIVE PRESSURE



- VARIATION OF PERMEABILITY WITH TIME

TEST NO. FE 11 Date: 24.4.75

DETAILS OF TEST MATERIAL

Fuller's earth remoulded in distilled water and allowed to soak for 24 hours before sedimenting direct into Cell.

TYPE OF TEST

Rate of loading; 10 psi/hr
Rate of unloading; 20 psi/hr
Salinity of initial pore fluid; non saline
Maximum consolidation pressure; 5000 psi

PROPOSED INVESTIGATION

Compaction of Ca^{-} montmorillonite at $60^{o}C$

INITIAL CONDITION OF SAMPLE

Thickness; 3.202 inch
Air dry weight; 452.9 g

FINAL CONDITION OF SAMPLE

Moisture content; 26.9 per cent
Thickness; 1.255 inch
Weight; 457.0 g

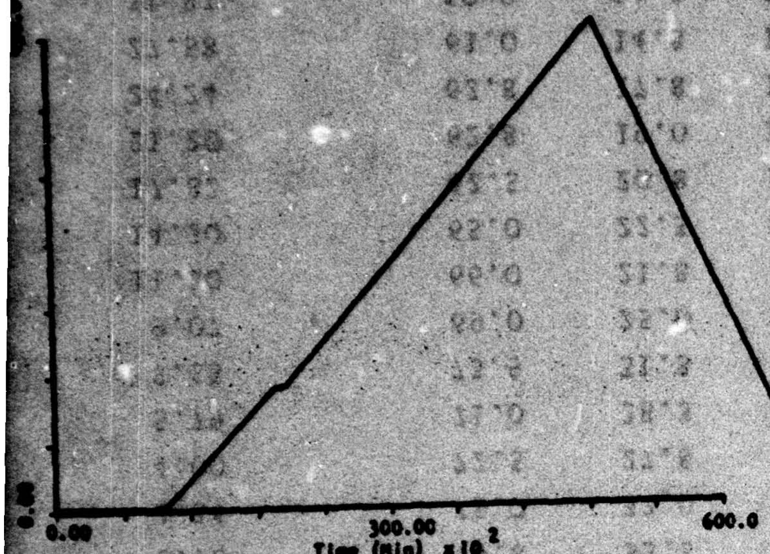
FURTHER COMMENTS

TABLE 7.3

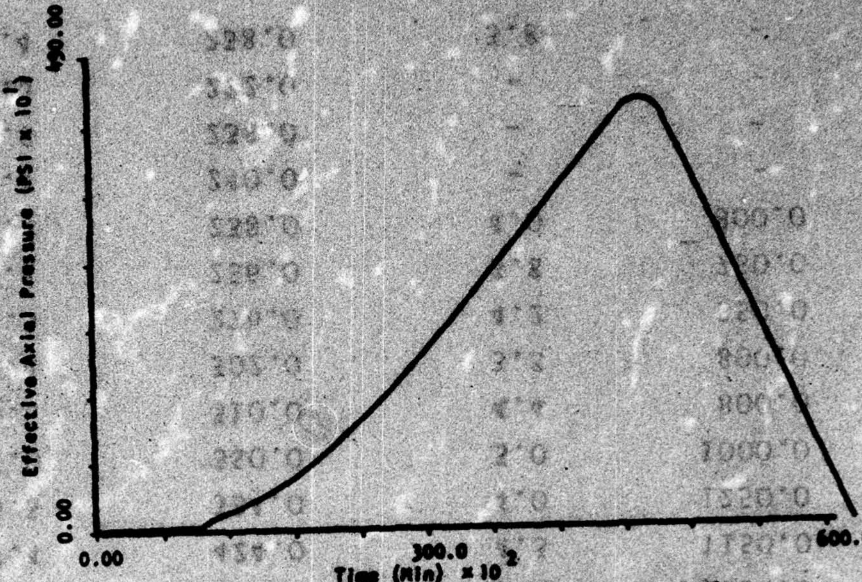
Results of chemical analysis of pore fluids expelled from FE 11

Axial Pressure MN/m^2	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
	Concentration mg/l						
0.01	79.0	30.5	246.3	10.1	700.0	7.2	1650.0
0.06	77.5	34.5	211.3	9.0	550.0	4.4	1350.0
0.12	77.3	32.5	197.5	8.8	486.0	3.5	950.0
0.19	73.5	32.0	197.5	8.6	500.0	5.1	950.0
0.28	75.8	34.0	201.3	9.0	490.0	4.0	900.0
0.43	72.5	30.0	192.5	8.6	502.0	4.4	950.0
0.70	74.8	33.5	197.5	7.8	470.0	2.9	1250.0
2.34	75.0	32.0	177.5	7.4	424.0	4.3	1150.0
4.00	72.5	27.8	170.0	8.3	384.0	4.0	1250.0
5.79	71.0	28.3	160.0	7.0	350.0	3.0	1000.0
7.55	73.5	31.3	146.3	6.5	310.0	4.4	800.0
9.07	69.0	25.0	146.3	6.4	302.0	3.3	800.0
11.20	66.0	21.8	121.3	7.3	276.0	4.2	550.0
14.20	65.0	22.3	136.5	6.4	256.0	3.8	750.0
17.82	62.5	20.8	132.5	6.4	238.0	4.0	800.0
21.20	62.8	19.0	135.0	6.4	240.0	-	-
24.24	62.8	17.8	136.5	6.8	238.0	-	-
27.58	61.0	14.8	138.8	7.6	222.0	-	-
31.83	60.0	14.5	142.5	7.4	238.0	3.8	-

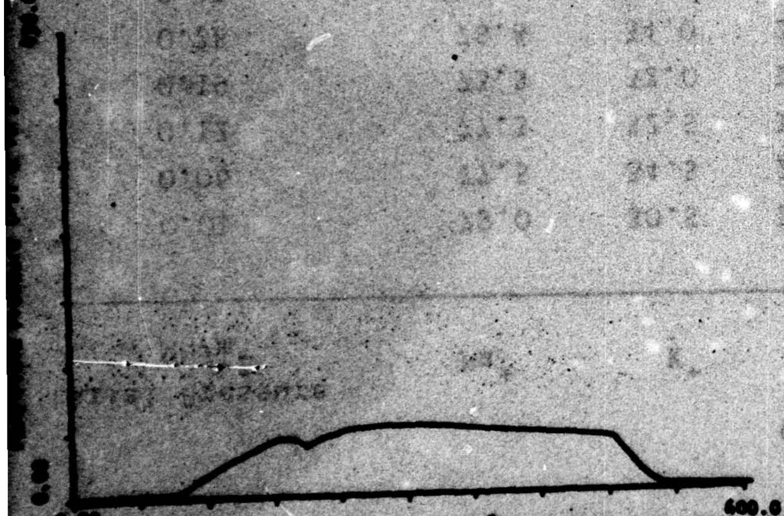
Test FE 11



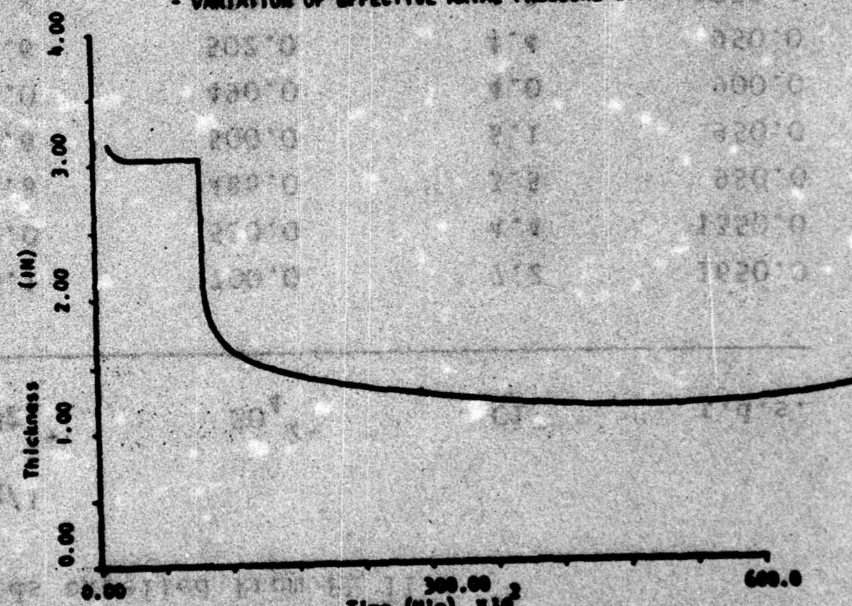
- VARIATION OF AXIAL PRESSURE WITH TIME



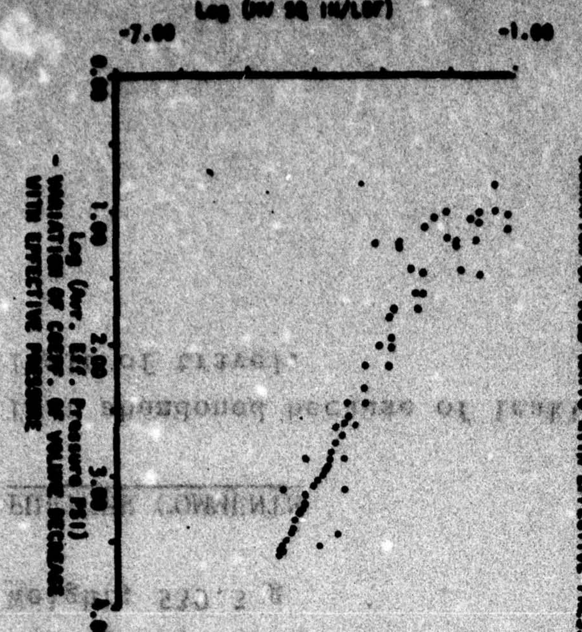
- VARIATION OF EFFECTIVE AXIAL PRESSURE WITH TIME



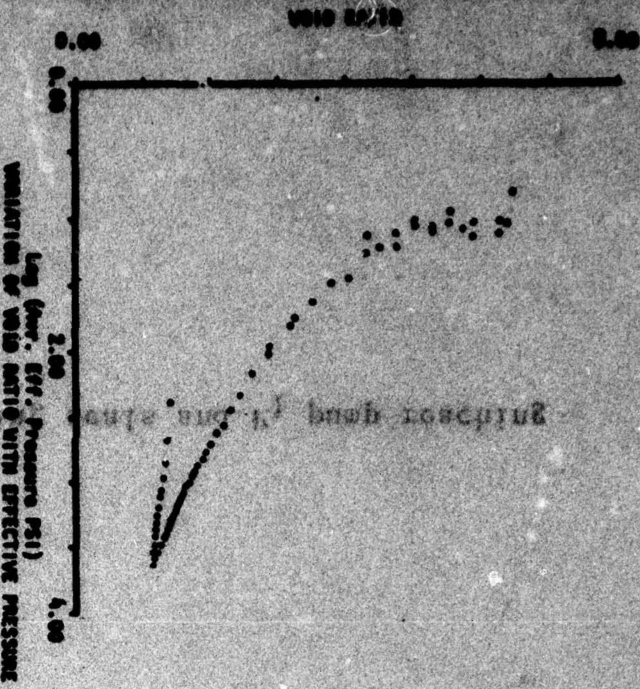
- VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME



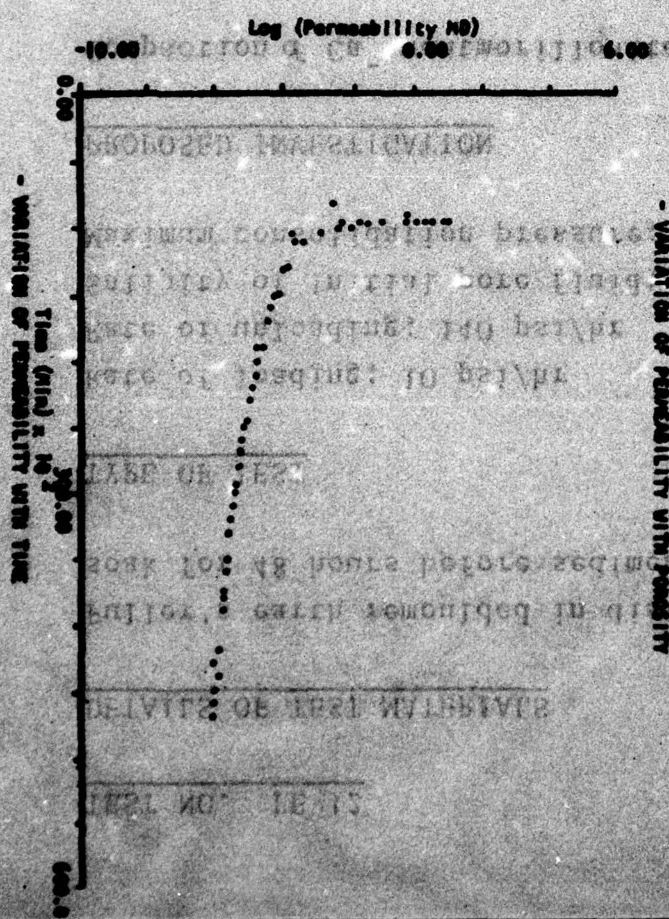
- CHANGE IN THICKNESS OF THE SAMPLE WITH TIME



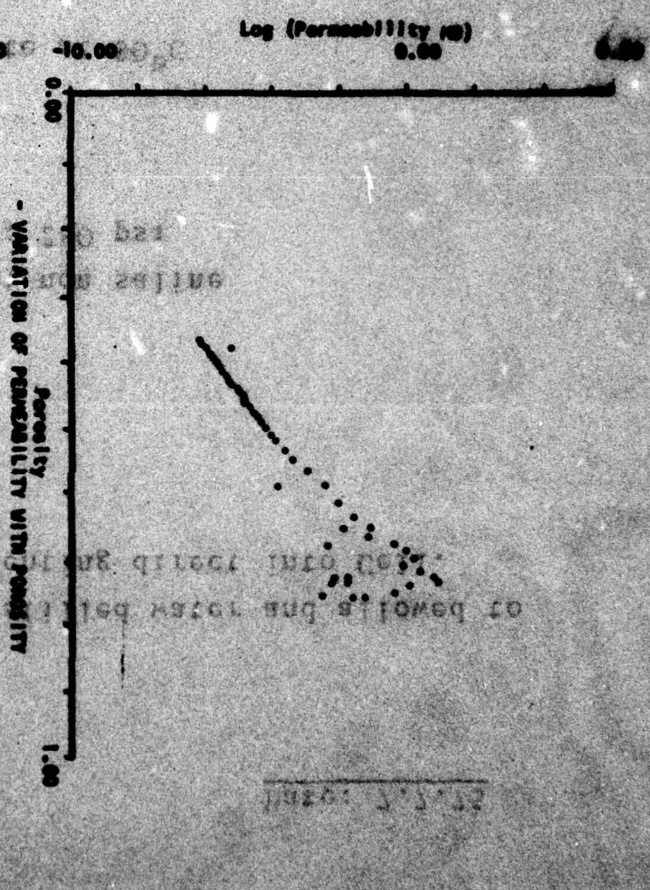
Log (DV SQ IN/LBF)
-7.00
-1.00
0.00
1.00
2.00
3.00
4.00
Log (Avr. Eff. Pressure PSI)
- VARIATION OF COEFF. OF VOLUME DECREASE
WITH EFFECTIVE PRESSURE



VOID RATIO
0.00
0.00
2.00
4.00
Log (Avr. Eff. Pressure PSI)
VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE



Log (Permeability MD)
-10.00
0.00
0.00
300.00
600.0
Time (Min) x 10
- VARIATION OF PERMEABILITY WITH TIME



Log (Permeability MD)
-10.00
0.00
0.00
1.00
Porosity
- VARIATION OF PERMEABILITY WITH POROSITY

TEST NO. FE 12 **Date: 7.7.75**

DETAILS OF TEST MATERIALS

Fuller's earth remoulded in distilled water and allowed to soak for 48 hours before sedimenting direct into Cell.

TYPE OF TEST

Rate of loading; 10 psi/hr
Rate of unloading; 140 psi/hr
Salinity of initial pore fluid; non saline
Maximum consolidation pressure; 280 psi

PROPOSED INVESTIGATION

Compaction of Ca^{-} montmorillonite at $80^{o}C$

INITIAL CONDITION OF SAMPLE

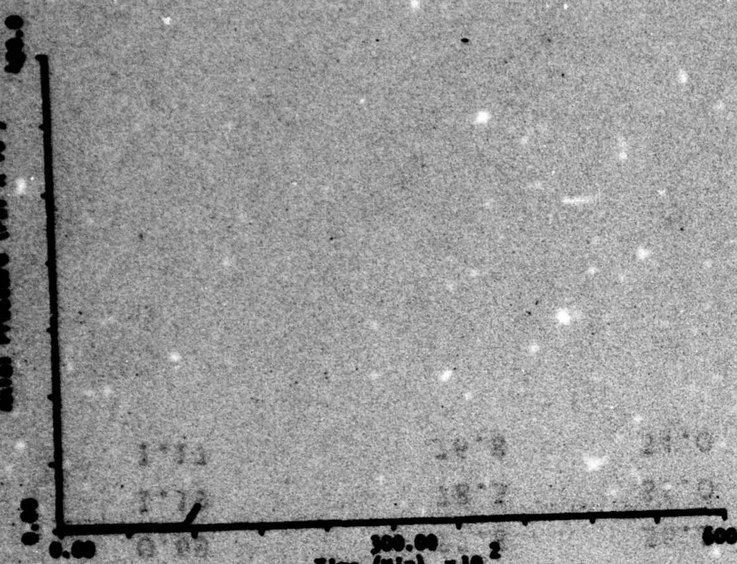
Thickness; 3.420 inches
Air dry weight; 481.6 g

FINAL CONDITION OF SAMPLE

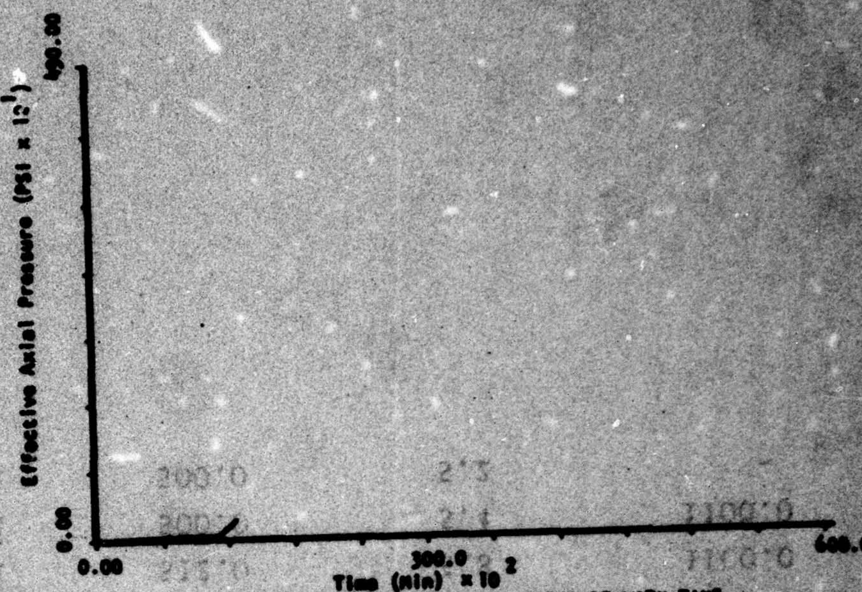
Moisture content; 59.7 per cent
Thickness; 1.693 inch
Weight; 539.3 g

FURTHER COMMENTS

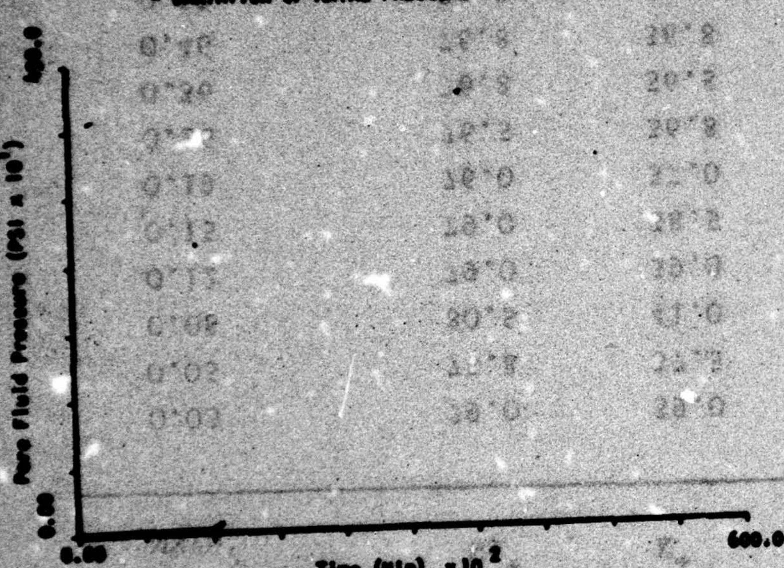
Test abandoned because of leaking seals and P_1 pump reaching limit of travel.



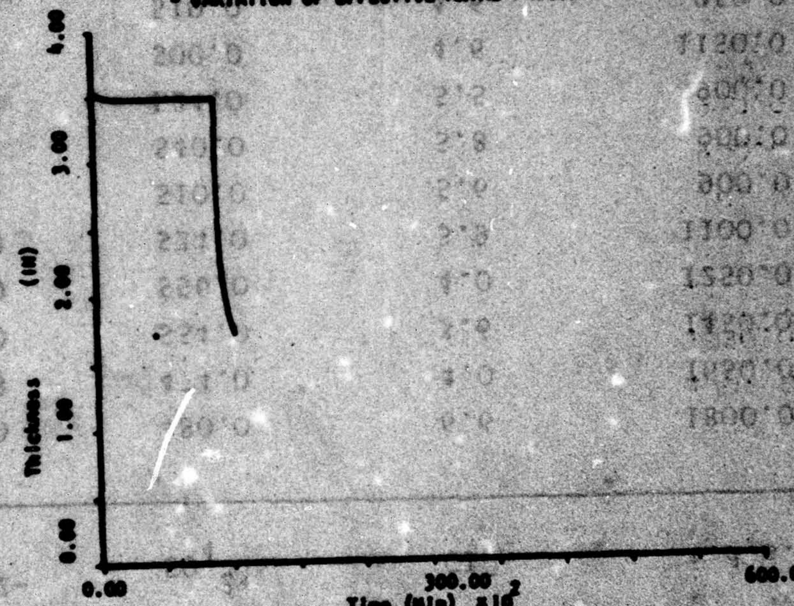
- VARIATION OF AXIAL PRESSURE WITH TIME



- VARIATION OF EFFECTIVE AXIAL PRESSURE WITH TIME



- VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME



- CHANGE IN THICKNESS OF THE SAMPLE WITH TIME

Test FE 12

TABLE .4

Results of chemical analysis of pore fluids expelled from FE 12

Axial Pressure MN/m^2	Concentration mg/l Na^+	K^+	Ca^{2+}	Mg^{2-}	SO_4^{2+}	Cl^-	t.d.s.
0.03	79.0	39.0	190.0	7.0	480.0	6.6	1800.0
0.05	75.8	37.5	187.5	6.8	474.0	4.0	1650.0
0.08	80.5	41.0	200.0	7.0	554.0	3.6	1450.0
0.12	79.0	39.0	195.0	7.0	556.0	4.0	1250.0
0.15	79.0	38.5	192.5	7.0	524.0	3.9	1100.0
0.19	76.0	37.0	185.0	7.4	510.0	5.6	900.0
0.26	76.5	36.8	186.3	7.1	540.0	5.8	900.0
0.36	76.8	36.5	190.0	7.1	524.0	5.5	900.0
0.46	76.8	36.8	186.3	7.0	500.0	4.6	1150.0
0.57	78.0	36.8	190.0	7.4	510.0	4.6	950.0
0.69	77.8	36.5	185.0	7.1	512.0	5.8	1100.0
1.19	78.5	35.0	181.3	7.1	500.0	5.4	1100.0
1.17	76.8	34.0	185.0	7.1	500.0	5.2	-

TEST NO. FE 13 **Date: 18.7.75**

DETAILS OF TEST MATERIAL

Fuller's earth remoulded in distilled water and allowed to soak for 48 hours before sedimenting direct into Cell.

TYPE OF TEST

Rate of loading; 10 psi/hr
Rate of unloading; 20 psi/hr
Salinity of initial pore fluid; non saline
Maximum consolidation pressure; 5000 psi

PROPOSED INVESTIGATION

Compaction of Ca^{++} montmorillonite at $80^{o}C$

INITIAL CONDITION OF SAMPLE

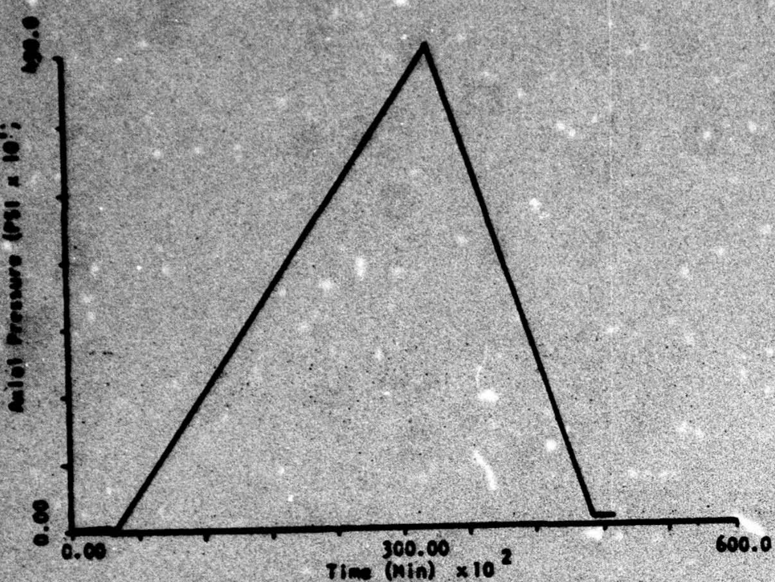
Thickness; 3.336 inches
Air dry weight; 444.5 g

FINAL CONDITION OF SAMPLE

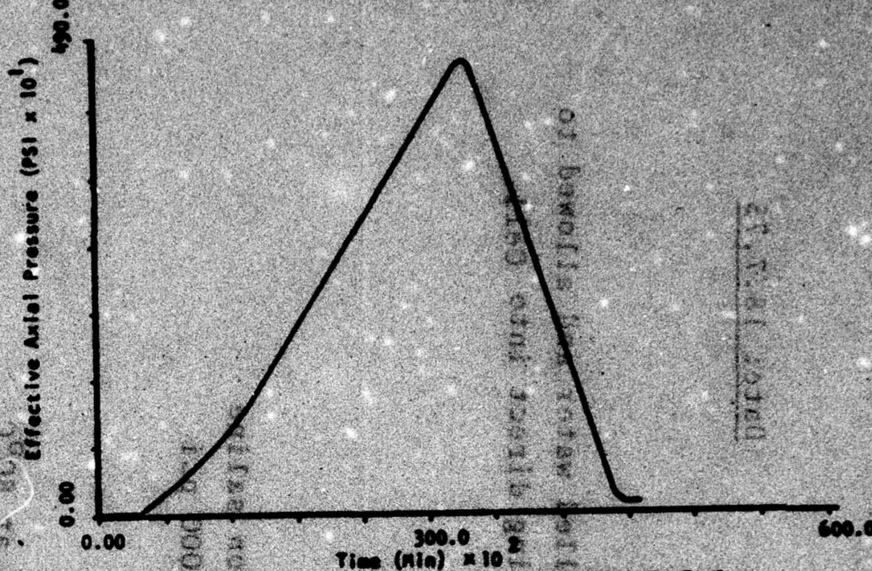
Moisture content; 36.1 per cent.
Thickness; 1.276 inch
Weight; 446.8 g

FURTHER COMMENTS

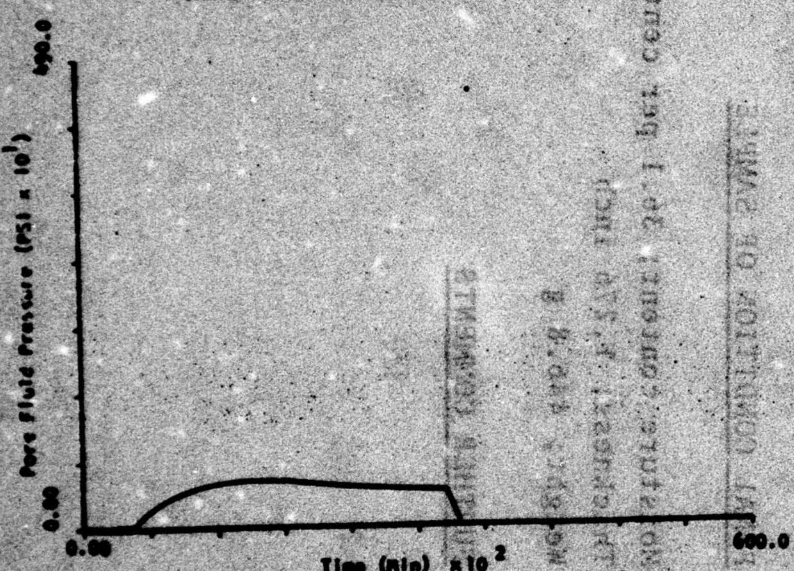
Test FE 13



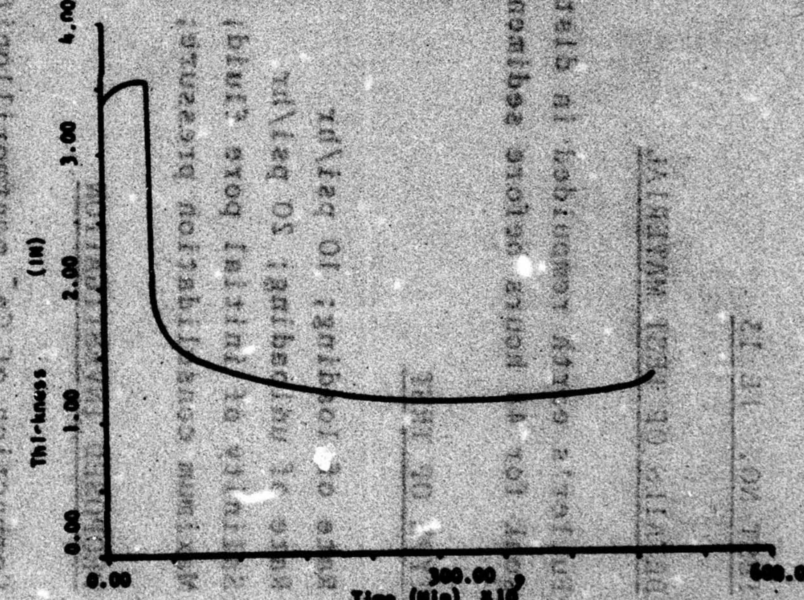
- VARIATION OF AXIAL PRESSURE WITH TIME



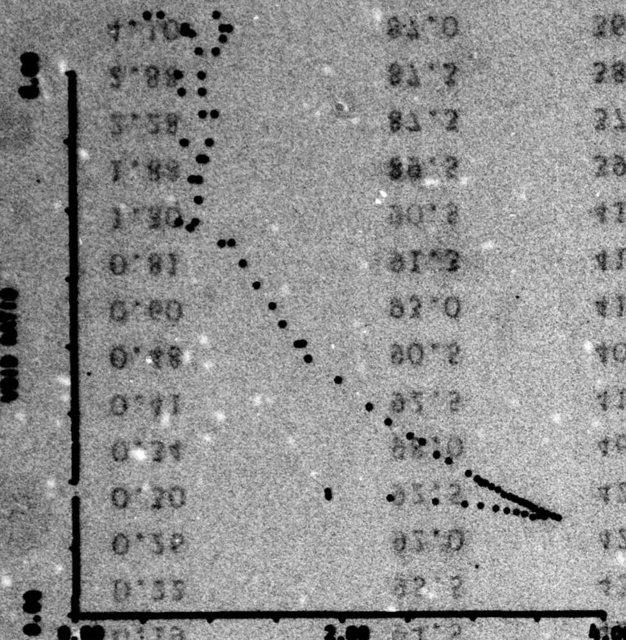
- VARIATION OF EFFECTIVE AXIAL PRESSURE WITH TIME



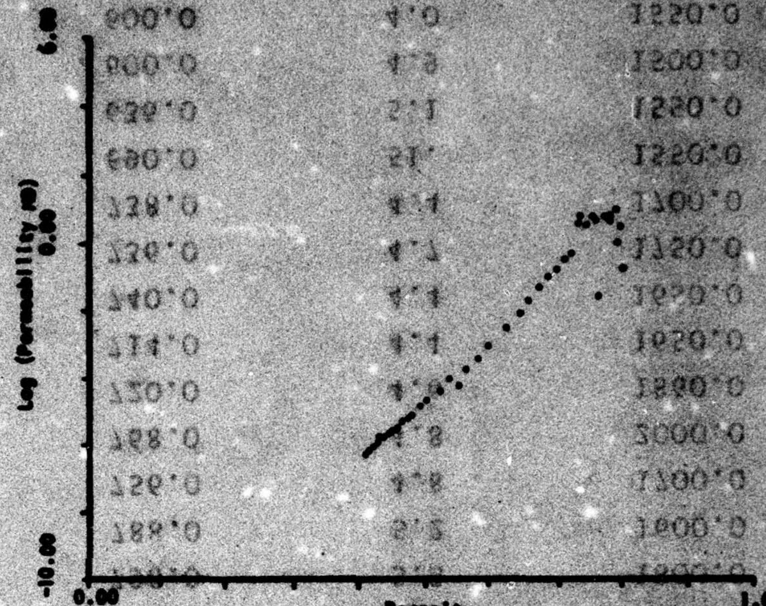
- VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME



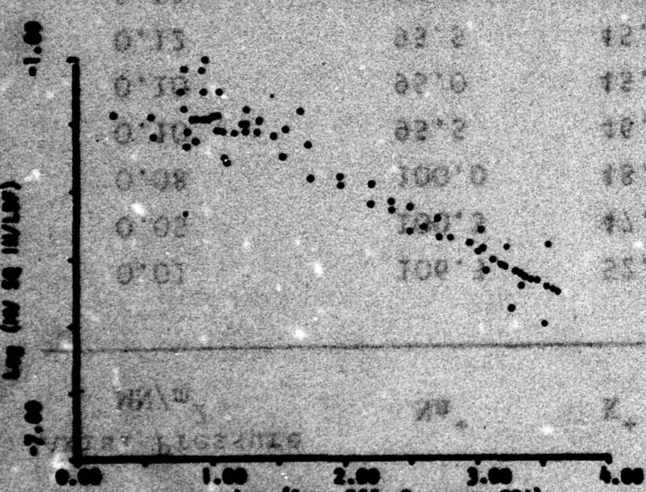
- CHANGE IN THICKNESS OF THE SAMPLE WITH TIME



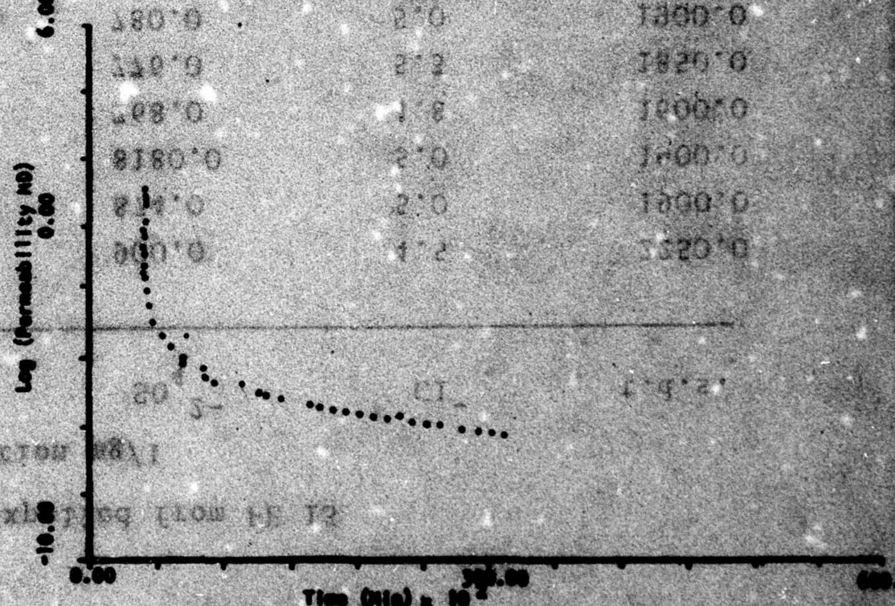
VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE



- VARIATION OF PERMEABILITY WITH POROSITY



- VARIATION OF COEFF. OF VOLUME DECREASE WITH EFFECTIVE PRESSURE



- VARIATION OF PERMEABILITY WITH TIME

TABLE 7.5

Results of chemical analysis of pore fluids expelled from FE 13

Axial Pressure MN/m^2	Contentration mg/1 Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
0.01	106.3	52.0	280.0	8.8	900.0	4.5	2250.0
0.05	100.3	47.5	265.3	9.3	874.0	5.0	1900.0
0.08	100.0	48.0	276.3	8.8	8180.0	5.0	1900.0
0.10	95.5	46.5	255.0	9.0	768.0	4.8	1600.0
0.10	95.0	45.5	260.0	9.0	776.0	5.3	1850.0
0.12	95.5	45.0	264.0	9.3	780.0	5.0	1900.0
0.15	95.0	44.2	267.5	9.0	790.0	5.2	1700.0
0.19	94.5	42.5	251.3	9.5	796.0	5.3	1800.0
0.22	95.5	43.8	251.3	9.5	788.0	5.2	1600.0
0.26	92.0	42.5	247.5	9.5	756.0	4.8	1700.0
0.30	92.5	42.0	247.5	9.5	768.0	4.8	2000.0
0.34	98.0	46.0	247.5	9.8	720.0	4.6	1860.0
0.41	92.5	41.5	245.0	9.8	714.0	4.4	1650.0
0.48	90.5	40.8	230.0	9.3	740.0	4.4	1650.0
0.60	93.0	41.2	240.0	9.8	736.0	4.7	1750.0
0.81	91.3	41.0	230.0	9.8	738.0	4.4	1700.0
1.30	90.5	41.0	220.0	9.5	690.0	51.	1550.0
1.88	89.5	39.5	220.0	9.3	636.0	5.1	1550.0
2.28	87.3	37.8	210.0	9.5	600.0	4.9	1500.0
2.88	87.3	38.0	201.3	9.0	600.0	4.0	1550.0
4.10	87.0	36.5	197.5	9.3	538.0	4.7	1350.0
5.83	85.0	32.8	185.0	9.0	502.0	4.3	1150.0
8.78	82.3	31.0	172.5	9.3	434.0	4.3	1250.0
11.34	85.8	32.0	178.3	9.3	422.0	6.8	-

TABLE 7.5 (continued)

12.76	83.5	30.2	170.0	9.0	362.0	4.4	1000.0
14.65	89.5	34.5	163.5	9.9	330.0	7.0	811.0
17.22	85.0	27.5	170.0	9.5	340.0	4.7	1200.0
20.73	83.5	25.5	174.0	9.8	330.0	10.1	1900.0
24.13	82.0	23.5	174.0	10.5	300.0	-	-
27.30	85.8	27.2	174.0	10.8	330.0	-	-
31.79	82.0	21.0	180.0	11.8	302.0	10.8	-

TEST NO. FE 16 Date: 27.8.75

DETAILS OF TEST MATERIAL

Fuller's earth remoulded in saline water and allowed to soak for 5 days before sedimenting direct into Cell.

TYPE OF TEST

Rate of loading; 10 psi/hr
Rate of unloading; 20 psi/hr
Salinity of initial pore fluid; unit salinity
Maximum consolidation pressure; 5710 psi held for 3 days

PROPOSED INVESTIGATION

Compaction of Ca^{-} montmorillonite at $40^{\circ}C$

INITIAL CONDITION OF SAMPLE

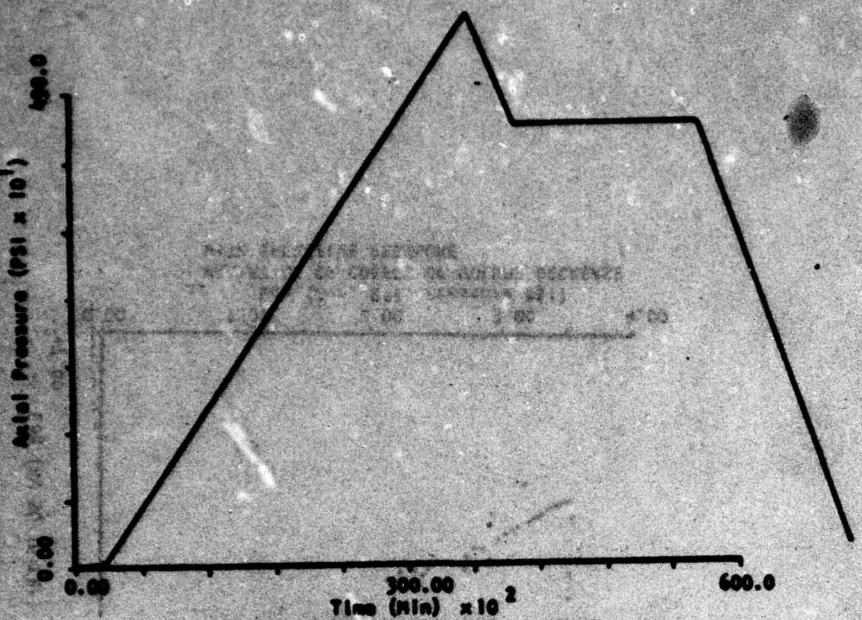
Thickness; 3.364 inches
Air dry weight; 413.2 g

FINAL CONDITION OF SAMPLE

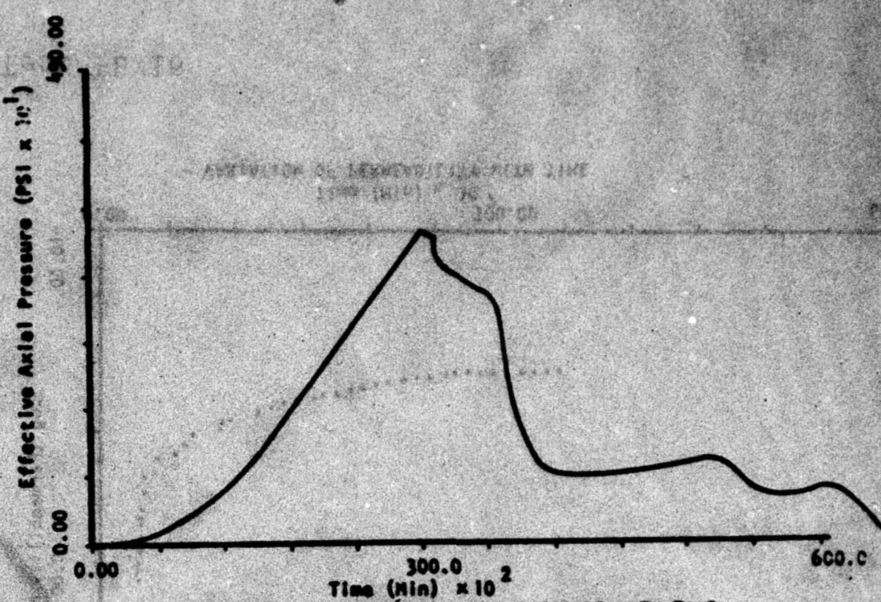
Moisture content; 26.2 per cent
Thickness; 1.102 inch
Weight; 412.9 g

FURTHER COMMENTS

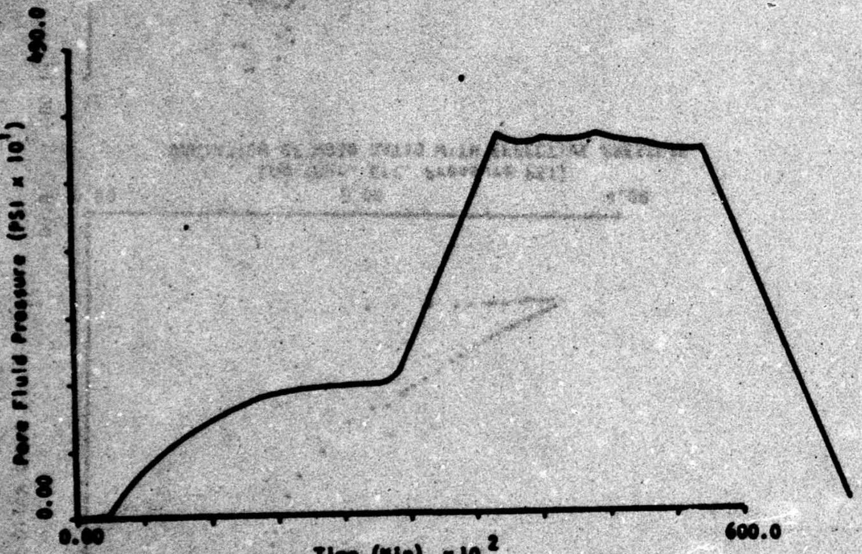
Held at 5710 psi for 3 days then unloaded at 20 psi/hr to 4590 psi which was held for 9 days.



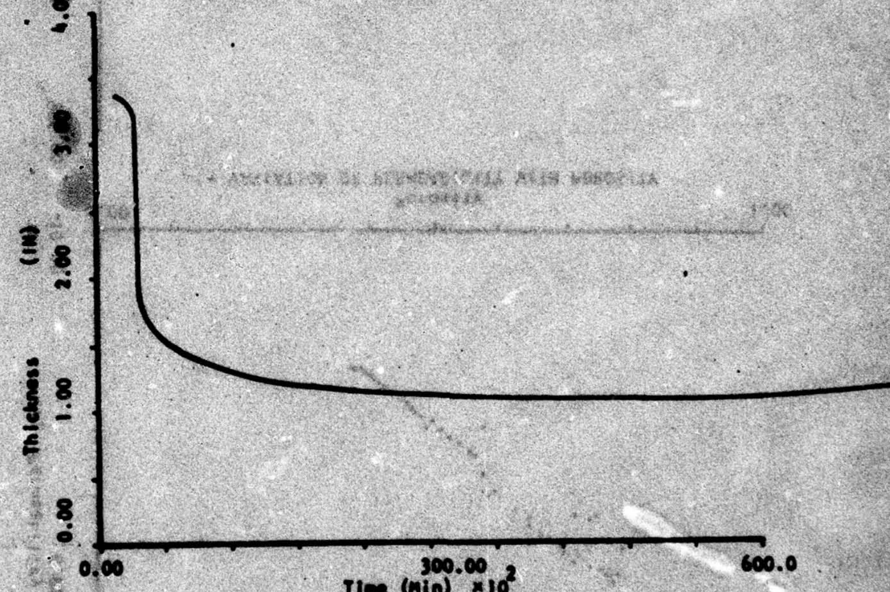
- VARIATION OF AXIAL PRESSURE WITH TIME



- VARIATION OF EFFECTIVE AXIAL PRESSURE WITH TIME

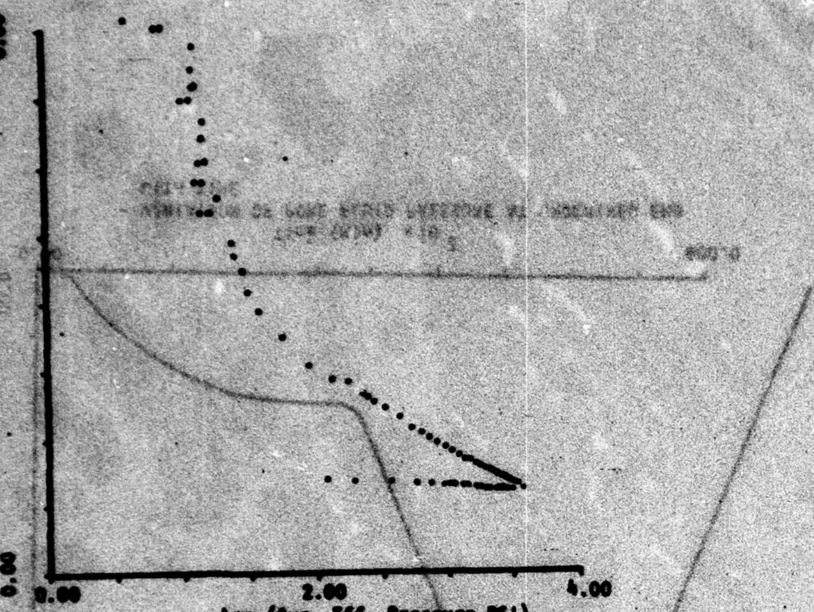


- VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME

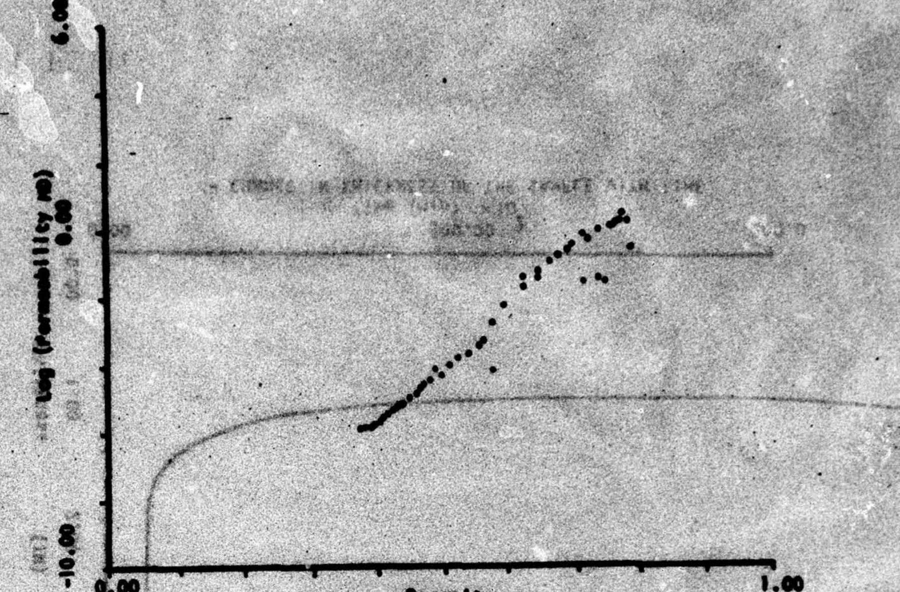


- CHANGE IN THICKNESS OF THE SAMPLE WITH TIME

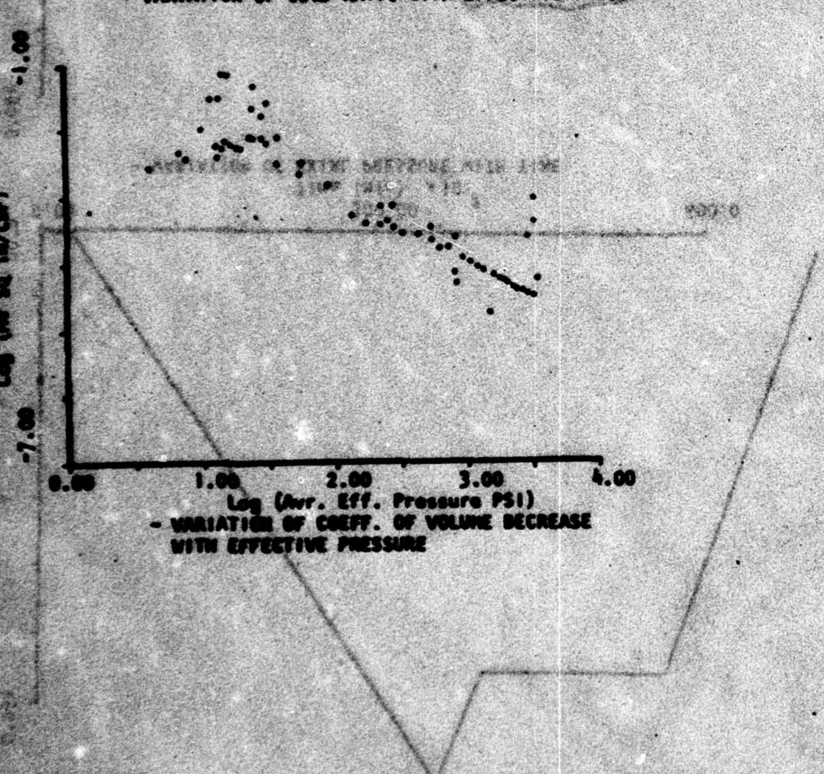
Test FL 10



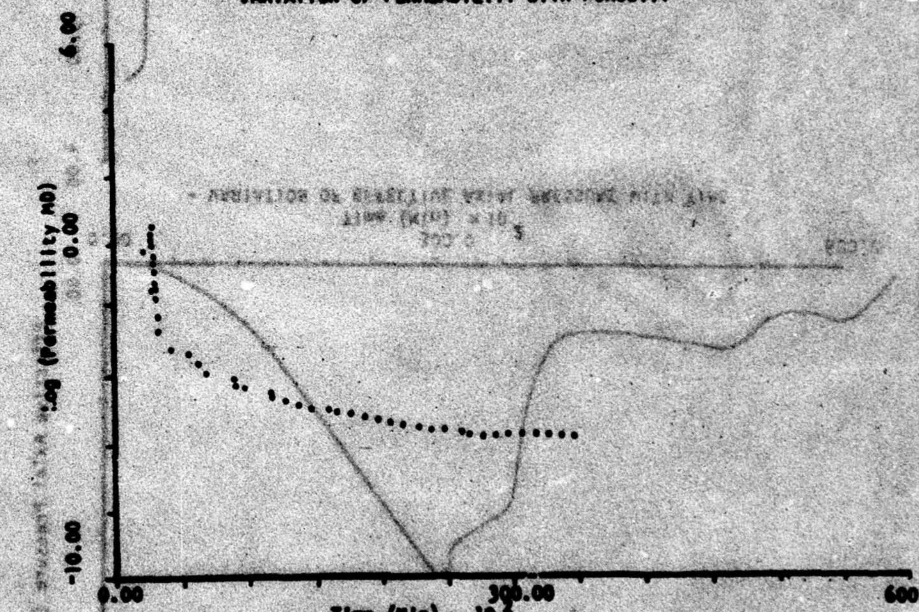
VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE



- VARIATION OF PERMEABILITY WITH POROSITY



- VARIATION OF COEFF. OF VOLUME DECREASE WITH EFFECTIVE PRESSURE



- VARIATION OF PERMEABILITY WITH TIME

Test FE 16

TABLE 7.6

Results of chemical analysis of pore fluids expelled from FB 16

Axial Pressure MN/m^2	Concentration mg/1 Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
0.01	10640.0	226.0	1410.0	1060.0	2646.0	19160.0	41950.0
0.05	9680.0	245.0	3060.0	975.0	2030.0	21210.0	45800.0
0.08	9880.0	241.0	3060.0	960.0	2110.0	21450.0	46150.0
0.12	9480.0	251.0	3040.0	955.0	2160.0	21360.0	47250.0
0.14	9020.0	243.0	2990.0	935.0	2120.0	21260.0	47000.0
0.17	9560.0	250.0	3060.0	960.0	2120.0	21070.0	45750.0
0.21	9560.0	233.0	2990.0	930.0	2120.0	21070.0	46300.0
0.24	9160.0	240.0	3040.0	930.0	2120.0	21070.0	46600.0
0.28	9180.0	232.0	2880.0	910.0	2080.0	20980.0	46500.0
0.31	9180.0	240.0	2960.0	930.0	1960.0	21070.0	47350.0
0.34	9160.0	241.0	2920.0	930.0	1960.0	20880.0	46400.0
0.39	9280.0	243.0	2990.0	930.0	2120.0	20880.0	46050.0
0.46	8880.0	240.0	2990.0	930.0	2100.0	20590.0	47200.0
0.55	9280.0	250.0	3020.0	920.0	2160.0	20980.0	47200.0
0.66	9540.0	235.0	2960.0	920.0	2190.0	20780.0	47350.0
0.79	9760.0	238.0	2990.0	910.0	2216.0	20880.0	46050.0
1.27	9560.0	236.0	2920.0	920.0	2216.0	20500.0	45550.0
1.86	9140.0	231.0	2850.0	900.0	2160.0	20590.0	45350.0
2.76	9040.0	229.0	2820.0	910.0	2160.0	20300.0	45900.0
3.80	8800.0	226.0	2780.0	930.0	2260.0	20020.0	45200.0
4.53	8620.0	215.0	2660.0	915.0	2160.0	19820.0	44850.0
5.48	8680.0	216.0	2660.0	900.0	2140.0	19540.0	44250.0
6.46	8760.0	200.0	2620.0	905.0	2140.0	19160.0	43300.0
7.70	8240.0	190.0	2550.0	905.0	2210.0	18580.0	43300.0

TABLE 7.6 (continued)

9.27	7480.0	196.0	2500.0	895.0	2220.0	18390.0	41500.0
10.98	7480.0	190.0	2360.0	855.0	2190.0	17430.0	40550.0
12.74	7680.0	182.0	2270.0	855.0	2160.0	17060.0	39550.0
14.44	7280.0	162.0	2100.0	795.0	2200.0	16570.0	39700.0
16.07	7320.0	163.0	2160.0	830.0	2260.0	15800.0	-
17.75	6880.0	150.0	1990.0	770.0	2340.0	15420.0	33200.0
19.46	6660.0	152.0	1990.0	760.0	2260.0	14940.0	34400.0
21.15	6680.0	136.0	1800.0	745.0	2280.0	12740.0	-
22.93	6160.0	145.0	1760.0	680.0	2260.0	12640.0	-
24.98	6320.0	150.0	1710.0	715.0	2300.0	11490.0	-
27.43	6520.0	131.0	1650.0	690.0	2300.0	13120.0	-
29.60	5880.0	128.0	1600.0	655.0	1970.0	-	-
32.17	5760.0	120.0	1550.0	650.0	2210.0	12450.0	35350.0
35.83	5680.0	114.0	1500.0	630.0	2210.0	11970.0	-
38.54	4180.0	96.0	1150.0	450.0	-	-	-

TEST NO. FE 22 Date: 31.10.75

DETAILS OF TEST MATERIAL

Fuller's earth remoulded in distilled water and allowed to soak for 6 days before sedimenting direct into Cell.

TYPE OF TEST

Rate of loading; 10 psi/hr
Rate of unloading; 15 psi/hr
Salinity of initial pore fluid; non saline
Maximum consolidation pressure; 320 psi

PROPOSED INVESTIGATION

Compaction of Ca^{-} montmorillonite at $20^{o}C$

INITIAL CONDITION OF SAMPLE

Thickness; 3.708 inches
Air dry weight; 430.5 g

FINAL CONDITION OF SAMPLE

Moisture content; 72.8 per cent
Thickness; 2.087 inches
Weight; 521.7 g

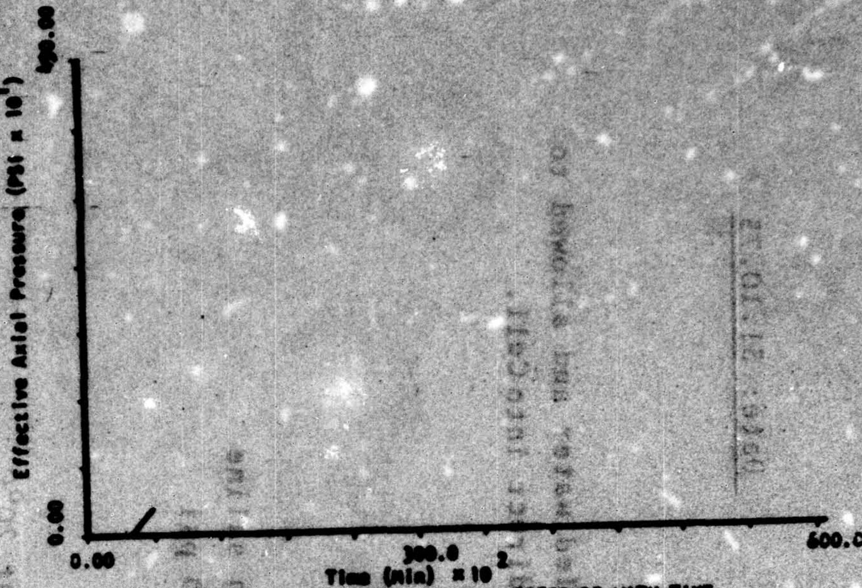
FURTHER COMMENTS

Test abandoned due to blockage and no movement of piston.

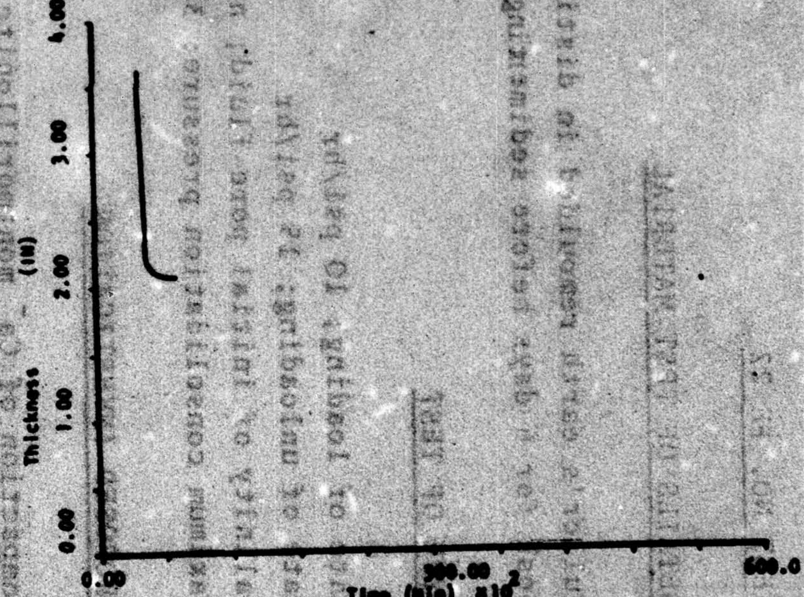
Test FE 22

- VARIATION OF AXIAL PRESSURE WITH TIME

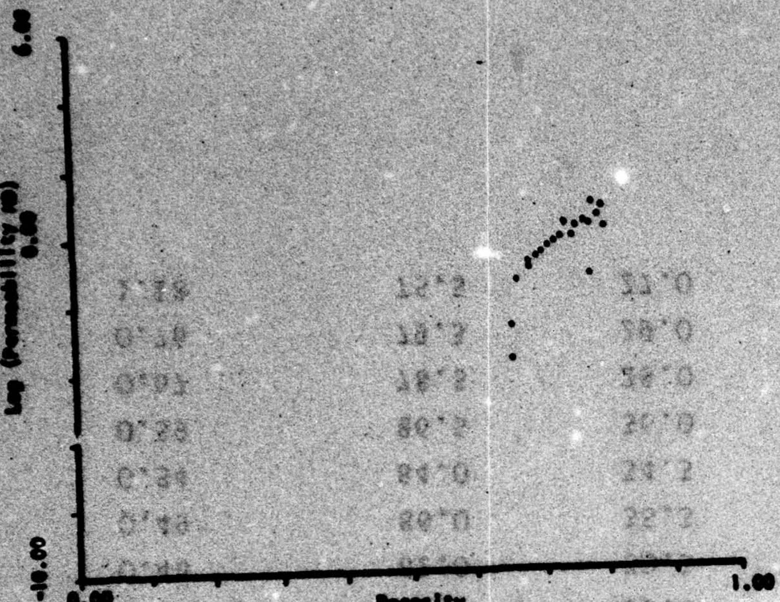
- VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME



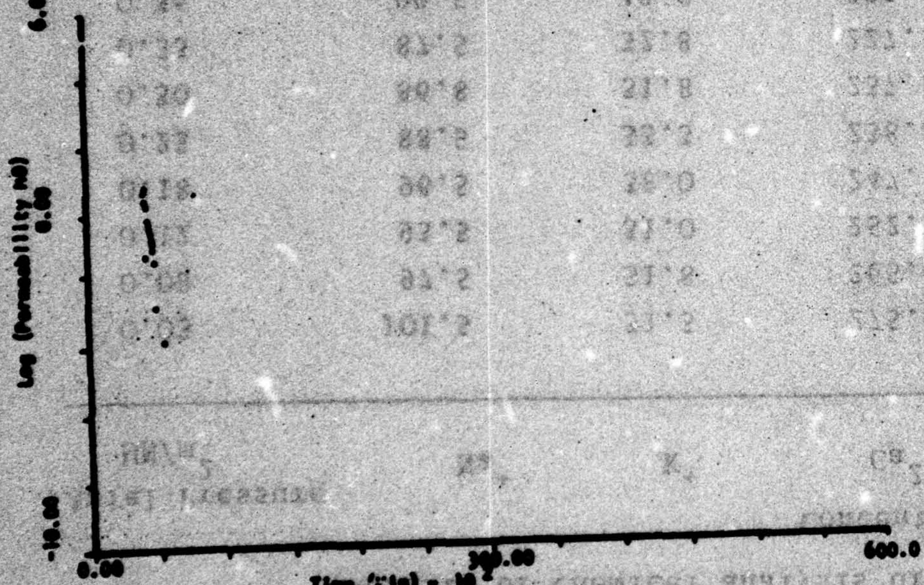
- VARIATION OF EFFECTIVE AXIAL PRESSURE WITH TIME



- CHANGE IN THICKNESS OF THE SAMPLE WITH TIME



- VARIATION OF PERMEABILITY WITH POROSITY



- VARIATION OF PERMEABILITY WITH TIME

Test FR 22

TABLE 7.7

Results of chemical analysis of pore fluids expelled from FE 22

Axial Pressure MN/m^2	Concentration mg/1 Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
0.03	101.5	31.3	275.0	13.5	740.0	17.7	2000.0
0.08	97.5	31.8	265.0	12.0	770.0	12.0	1900.0
0.12	93.5	31.0	252.5	11.6	714.0	11.4	1450.0
0.18	96.5	38.0	247.5	10.8	700.0	11.4	1300.0
0.25	88.5	33.3	238.8	10.0	660.0	11.6	950.0
0.30	86.8	31.8	237.5	9.3	620.0	10.8	1250.0
0.33	87.5	32.8	227.5	9.6	620.0	9.8	850.0
0.36	99.5	47.0	225.0	10.0	600.0	10.0	1000.0
0.40	90.3	38.0	221.3	9.6	590.0	9.8	1100.0
0.46	82.0	30.3	222.5	9.3	640.0	10.0	-
0.49	86.0	35.3	222.5	8.8	570.0	9.5	900.0
0.54	84.0	34.3	218.8	8.5	568.0	9.1	1500.0
0.59	86.5	36.0	210.0	8.5	570.0	8.4	1300.0
0.67	78.5	28.0	207.5	8.5	570.0	9.2	950.0
0.76	79.3	29.0	207.5	8.1	540.0	10.1	1200.0
1.18	75.5	27.0	202.5	7.8	530.0	10.4	950.0

TEST NO. FE 24

Date: 14.11.75

DETAILS OF TEST MATERIAL

Fuller's earth remoulded in saline water and allowed to soak for 5 days before sedimenting direct into Cell.

TYPE OF TEST

Rate of loading; 10 psi/hr
Rate of unloading; 100 psi/hr
Salinity of initial pore fluid; unit salinity
Maximum consolidation pressure; 5175 psi held for 6 days

PROPOSED INVESTIGATION

Compaction of Ca^{-} montmorillonite at $60^{o}C$

INITIAL CONDITION OF SAMPLE

Thickness; 2.709 inches
Air dry weight; 391.5 g

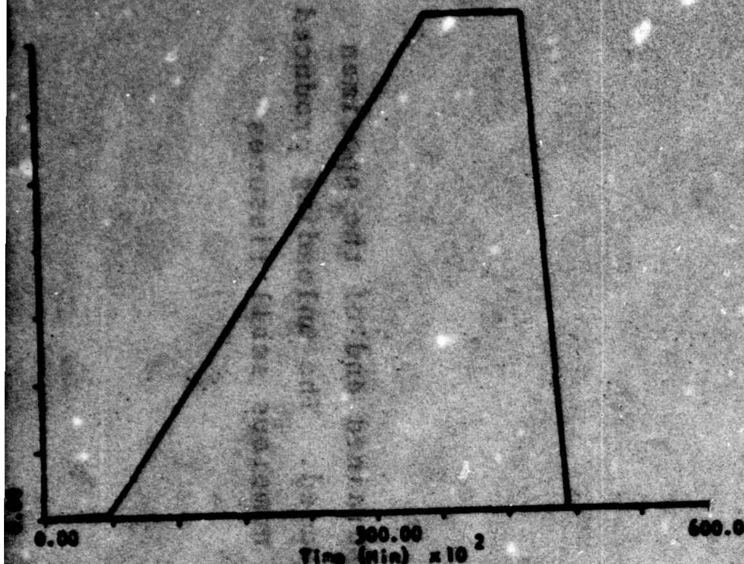
FINAL CONDITION OF SAMPLE

Moisture content; 31.5 per cent
Thickness; 1.024 inch
Weight- 382.82 g

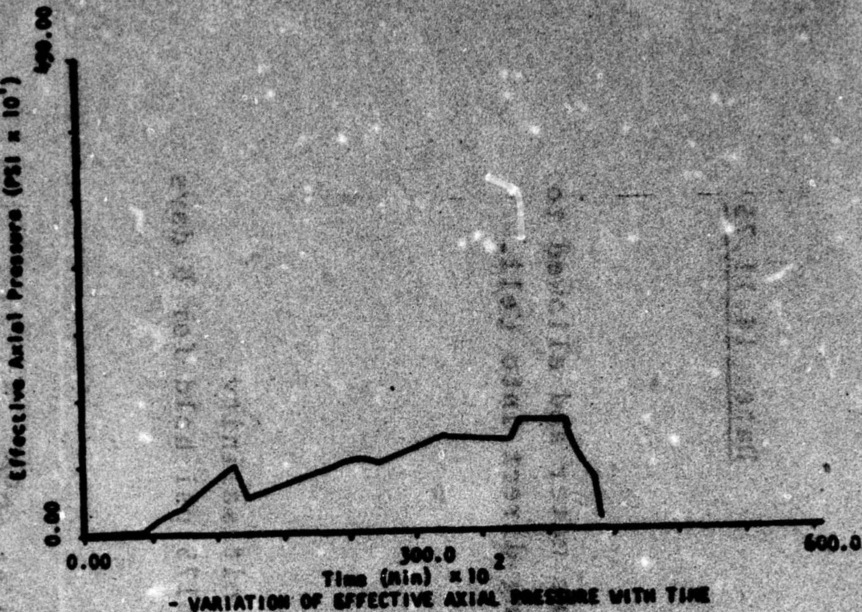
FURTHER COMMENTS

Silicone oil was present at the undrained end of the specimen and so the sample was rapidly unloaded. The unloading produced three major vertical fissures and numerous small fissures around the margin.

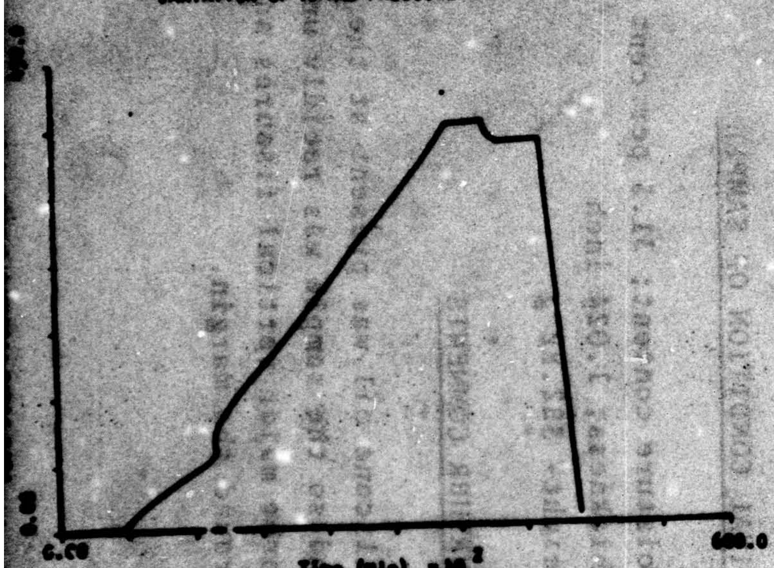
Test FE 24



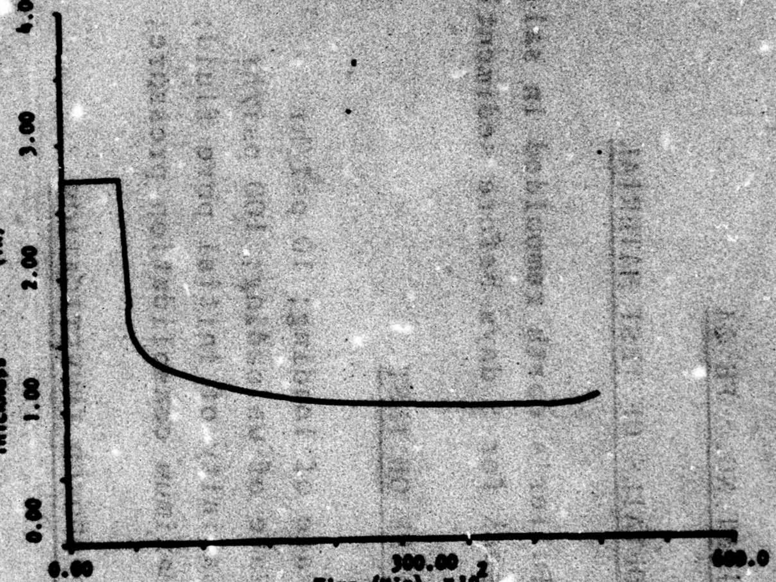
- VARIATION OF AXIAL PRESSURE WITH TIME



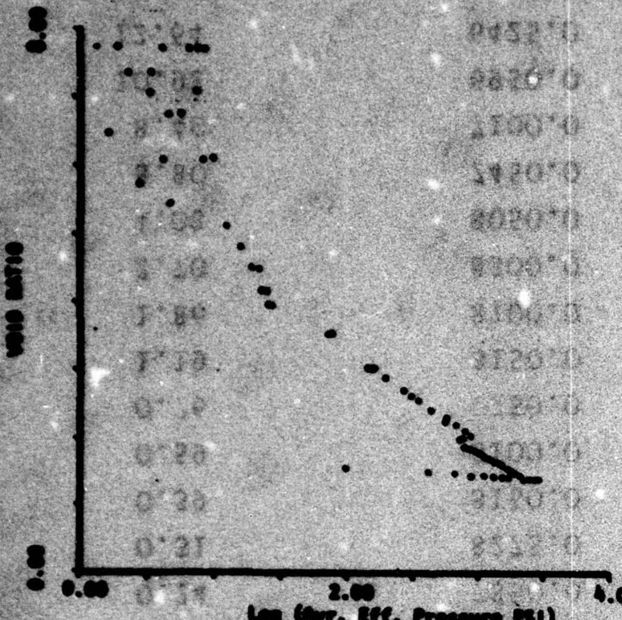
- VARIATION OF EFFECTIVE AXIAL PRESSURE WITH TIME



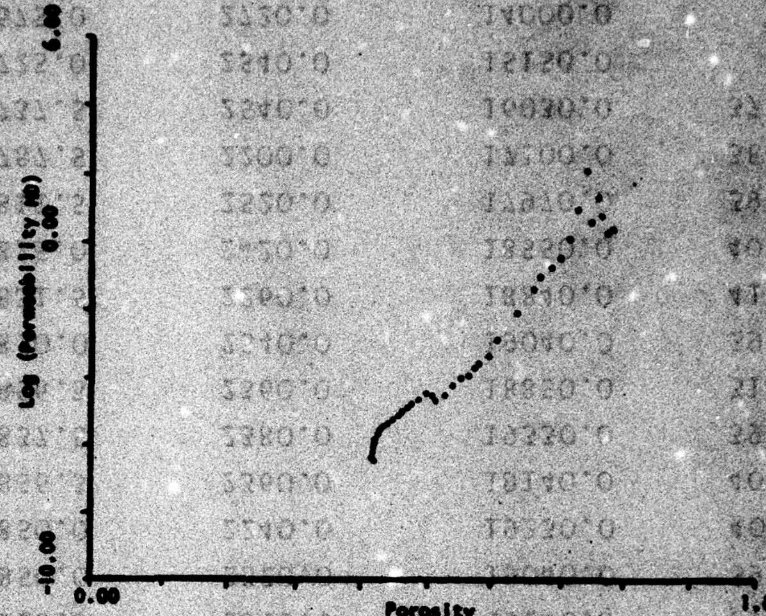
- VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME



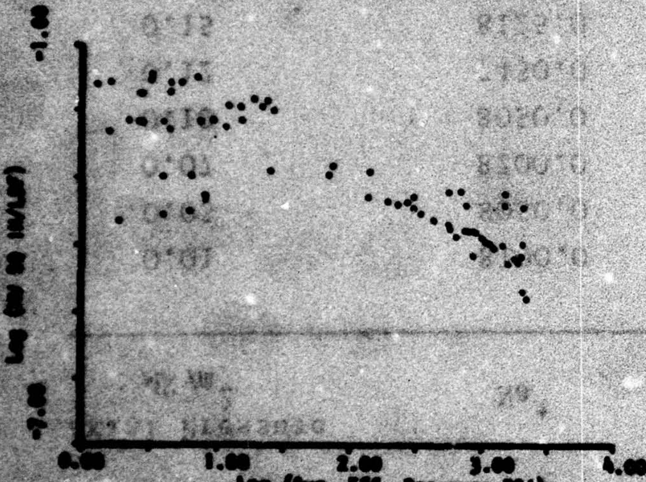
- CHANGE IN THICKNESS OF THE SAMPLE WITH TIME



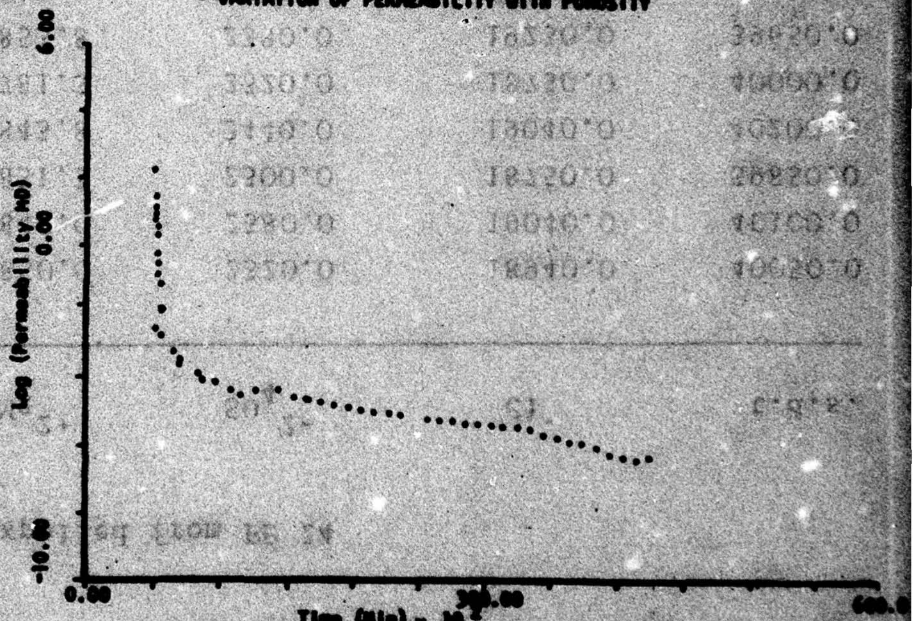
VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE



- VARIATION OF PERMEABILITY WITH POROSITY



- VARIATION OF COEFF. OF VOLUME DECREASE WITH EFFECTIVE PRESSURE



- VARIATION OF PERMEABILITY WITH TIME

TABLE 7.8

Results of chemical analysis of pore fluids expelled from FE 24

Axial Pressure MN/m^2	Concentration mg/1 Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
0.01	8100.0	364.4	2337.5	850.0	2320.0	18940.0	40050.0
0.03	8050.0	367.3	2287.5	845.0	2380.0	19040.0	40100.0
0.07	8200.0	362.5	3387.5	831.3	2300.0	18750.0	39850.0
0.10	8050.0	354.8	2325.0	843.8	2440.0	19040.0	40200.0
0.12	7450.0	326.9	2137.5	781.3	2320.0	18750.0	40000.0
0.15	8125.0	352.9	2325.0	853.8	2380.0	19230.0	39650.0
0.19	7700.0	339.4	2262.5	818.8	2340.0	19140.0	39900.0
0.24	7850.0	350.0	2312.5	850.0	2320.0	19040.0	39950.0
0.31	8275.0	350.0	2362.5	850.0	2240.0	19230.0	40500.0
0.39	8150.0	351.0	2250.0	856.3	2360.0	19140.0	40400.0
0.59	8100.0	343.3	2275.0	837.5	2380.0	19330.0	39650.0
0.76	7250.0	346.1	2337.5	856.3	2360.0	18850.0	31250.0
1.19	8150.0	344.3	2312.5	850.0	2340.0	19040.0	39650.0
1.86	8100.0	340.4	2225.0	831.5	2260.0	18840.0	41300.0
2.70	8300.0	333.6	2250.0	825.0	2420.0	18550.0	40750.0
4.08	8050.0	305.0	2137.5	812.5	2520.0	17970.0	39800.0
5.80	7450.0	324.0	2000.0	787.5	2200.0	17100.0	38650.0
8.40	7100.0	278.9	1862.5	737.5	2540.0	16030.0	37100.0
10.92	6950.0	262.5	1725.0	725.0	2540.0	15150.0	-
12.64	6425.0	237.5	1662.5	675.0	2720.0	14000.0	-
14.42	6525.0	229.8	1625.0	668.8	2700.0	14180.0	-
16.20	6000.0	211.5	1475.0	625.0	-	-	-

TABLE 7.8 (continued)

18.00	5950.0	205.8	1475.0	643.8	-	12240.0	-
20.50	5600.0	203.9	1412.5	625.0	2860.0	12340.0	-
23.78	5550.0	184.6	1300.0	575.0	-	11950.0	-
27.22	5600.0	176.0	1287.5	568.8	-	10490.0	-
31.68	5375.0	165.4	1225.0	556.3	-	10100.0	-

TEST NO. FE 27 Date: 9.1.76

DETAILS OF TEST MATERIAL

Fuller's earth remoulded in saline water and allowed to soak for 6 days before sedimenting direct into Cell.

TYPE OF TEST

Rate of loading; 10 psi/hr
Rate of unloading; 100 psi/hr
Salinity of initial pore fluid; unit salinity
Maximum consolidation pressure; 1620 psi

PROPOSED INVESTIGATION

Compaction Ca^{-} montmorillonite at $20^{o}C$

INITIAL CONDITION OF SAMPLE

Moisture content; 37.8 per cent
Thickness; 1.410 inch
Weight; 495.5 g

FURTHER COMMENTS

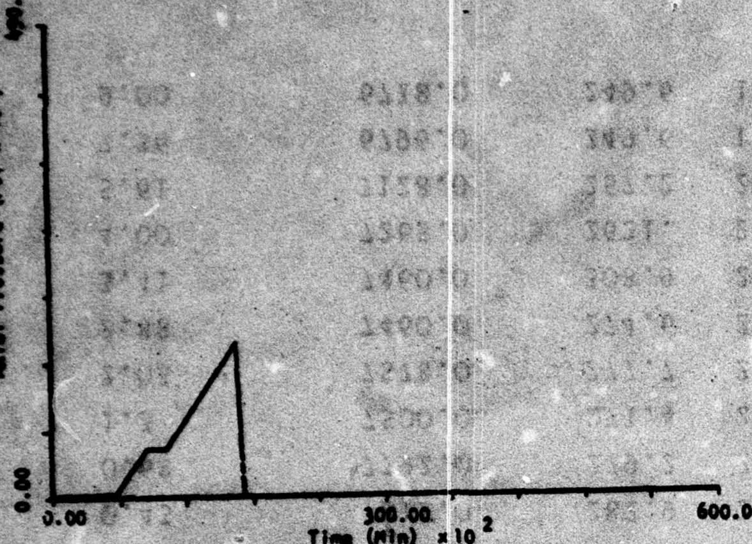
Test abandoned because of anomalous behaviour in pore fluid pressure.

TABLE 7.9

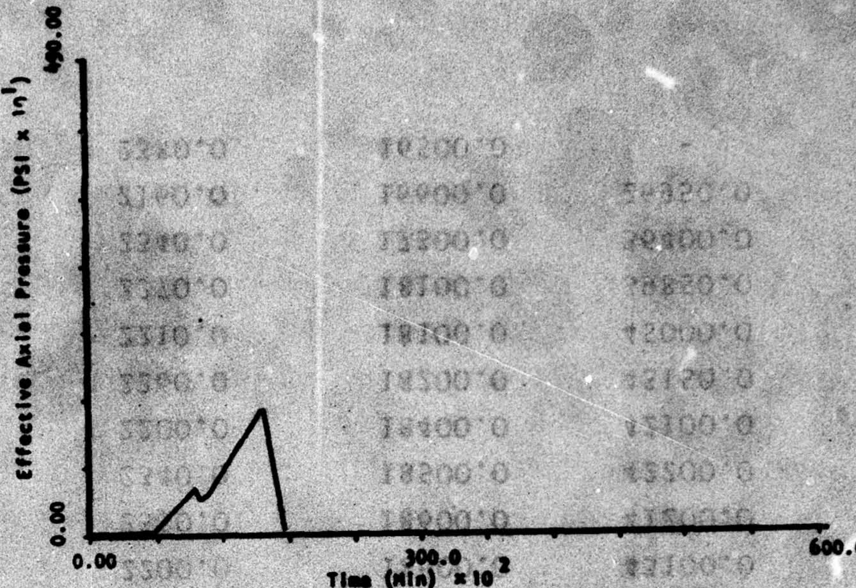
Results of chemical analysis of pore fluids expelled from FE 27

Axial Pressure MN/m^2	Concentration mg/l Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
0.01	7812.0	283.9	2418.0	826.8	2130.0	19000.0	43950.0
0.08	7714.0	290.0	2340.0	811.2	2200.0	19000.0	43150.0
0.10	8671.0	302.6	2580.0	881.4	2230.0	19200.0	44000.0
0.14	7792.0	280.8	2434.0	787.8	2270.0	19000.0	42600.0
0.22	9695.0	280.0	2309.0	787.8	2270.0	18800.0	42600.0
0.36	7734.0	280.8	2402.0	795.6	2300.0	18900.0	43650.0
0.43	7812.0	282.9	2262.0	787.8	2200.0	18600.0	43100.0
0.68	7792.0	279.2	2278.0	787.8	2330.0	18600.0	41200.0
1.3	7500.0	271.4	2262.0	780.0	2340.0	18500.0	42200.0
2.03	7578.0	277.7	2184.0	787.8	2200.0	18400.0	42100.0
2.88	7460.0	274.6	2122.0	787.8	2260.0	18200.0	43150.0
3.41	7460.0	308.9	2200.0	780.0	2210.0	18100.0	45000.0
4.00	7265.0	2621.	2153.0	772.2	2270.0	18100.0	39850.0
5.61	7128.0	257.2	2090.0	748.8	2340.0	17300.0	36400.0
7.36	6796.0	249.6	1981.0	725.4	2160.0	16600.0	26950.0
9.00	6718.0	249.6	1841.0	725.4	2380.0	16500.0	-

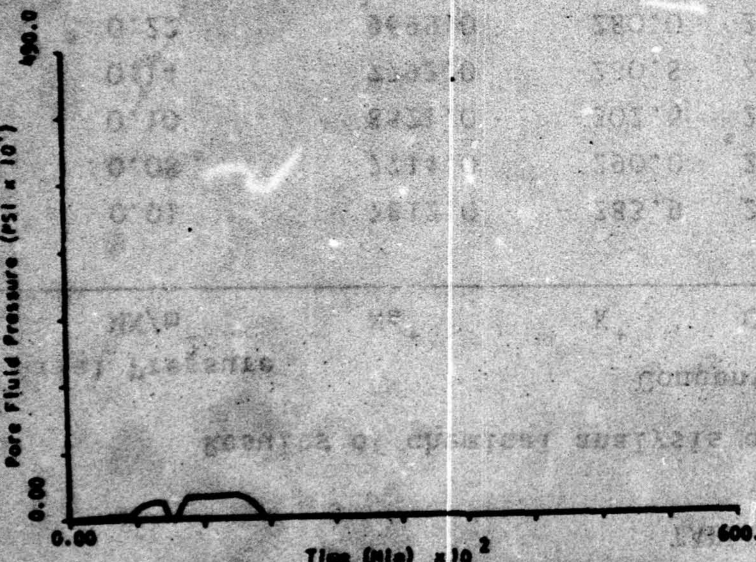
Test FE 27



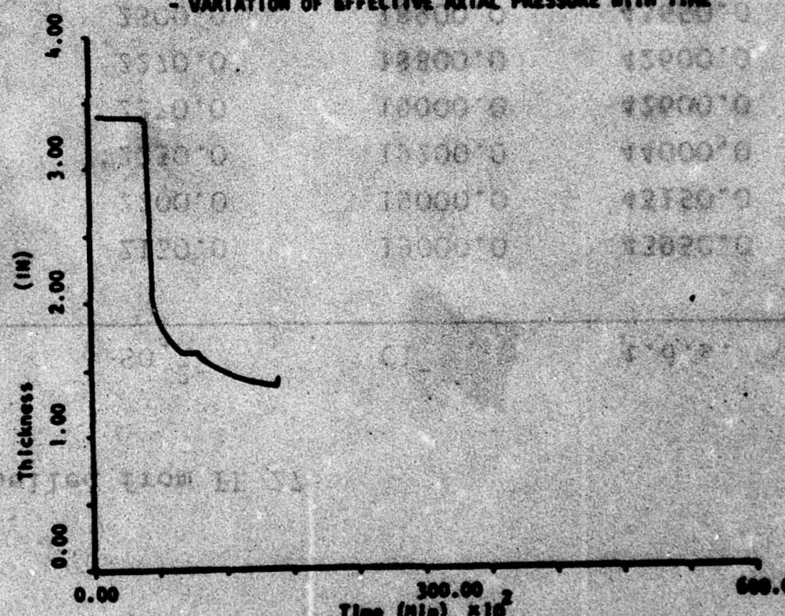
- VARIATION OF AXIAL PRESSURE WITH TIME



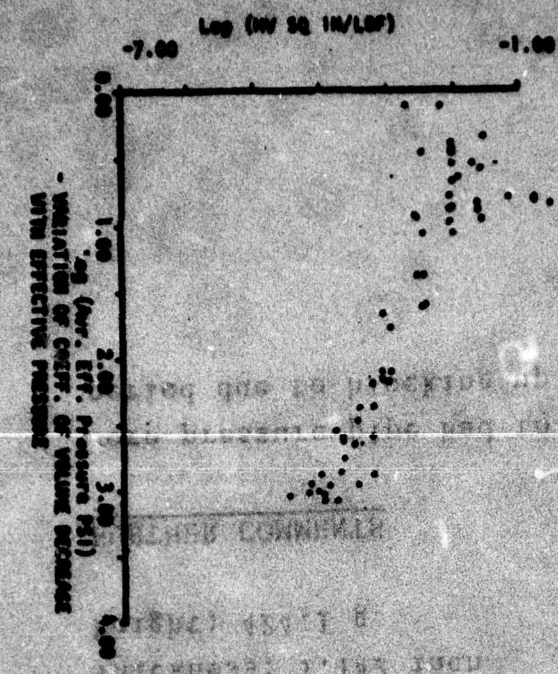
- VARIATION OF EFFECTIVE AXIAL PRESSURE WITH TIME

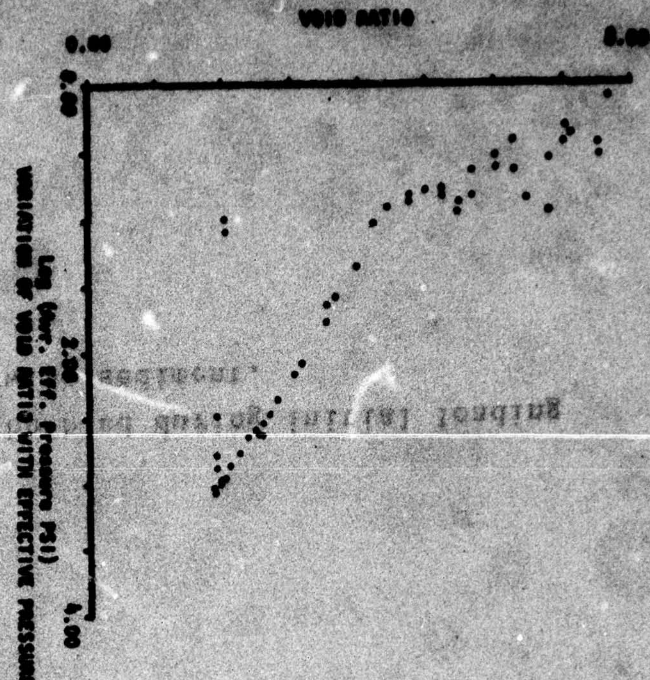


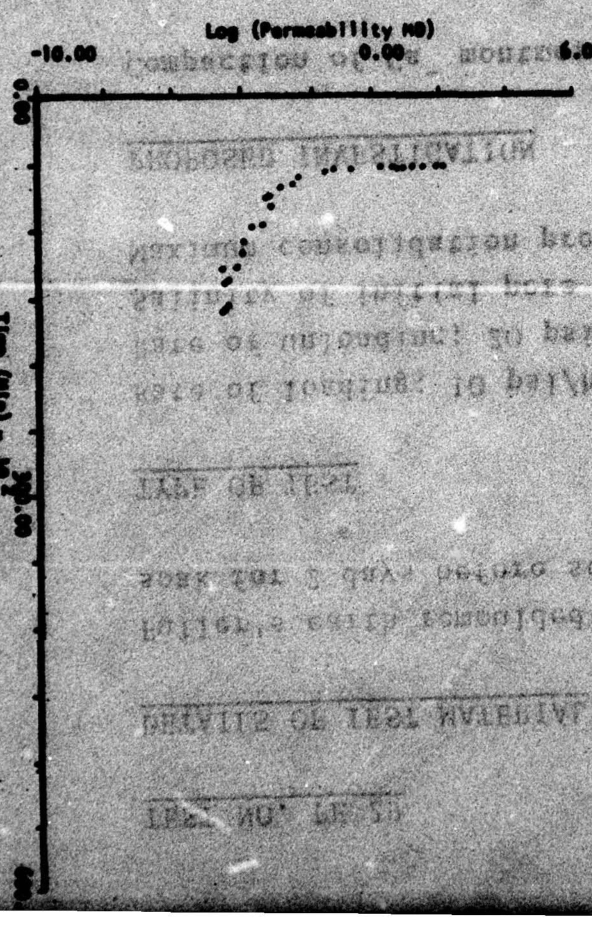
- VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME

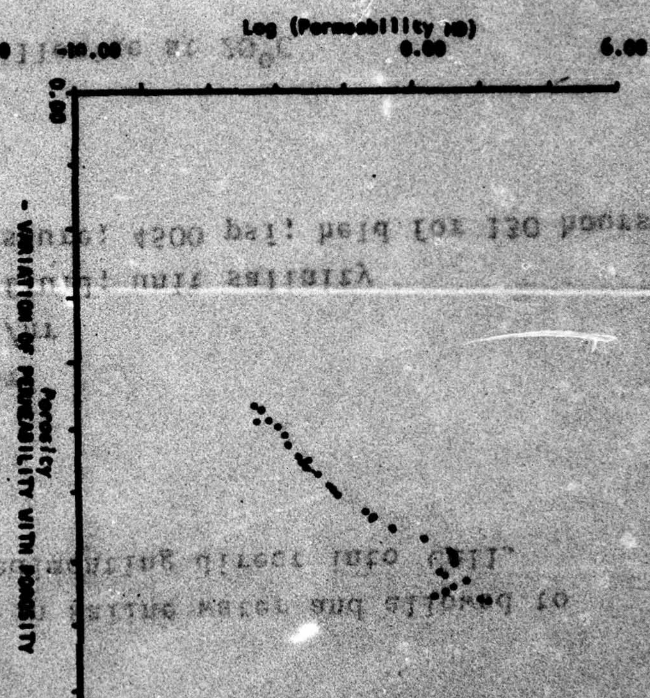


- CHANGE IN THICKNESS OF THE SAMPLE WITH TIME


Log (MV SQ IN/LBF)
-7.00
-1.00
0.00
1.00
2.00
3.00
4.00
Log (Av. Eff. Pressure PSI)
- VARIATION OF COEFF. OF VOLUME DECREASE WITH EFFECTIVE PRESSURE


VOID RATIO
0.00
6.00
0.00
2.00
4.00
Log (Av. Eff. Pressure PSI)
VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE


Log (Permeability mD)
-10.00
0.00
6.00
0.00
300.00
Time (Min) x 10
- VARIATION OF PERMEABILITY WITH TIME


Log (Permeability mD)
-10.00
0.00
6.00
0.00
1.00
Porosity
- VARIATION OF PERMEABILITY WITH POROSITY

TEST NO. FE 29 Date: 22.1.76

DETAILS OF TEST MATERIAL

Fuller's earth remoulded in saline water and allowed to soak for 2 days before sedimenting direct into Cell.

TYPE OF TEST

Rate of loading; 10 psi/hr
Rate of unloading; 20 psi/hr
Salinity of initial pore fluid; unit salinity
Maximum consolidation pressure; 4500 psi; held for 130 hours

PROPOSED INVESTIGATION

Compaction of Ca^{-} montmorillonite at $20^{o}C$

INITIAL CONDITION OF SAMPLE

Thickness; 3.376 inches
Air dry weight; 371.5 g

FINAL CONDITION OF SAMPLE

Moisture content; 29.0 per cent
Thickness; 1.142 inch
Weight; 424.1 g

FURTHER COMMENTS

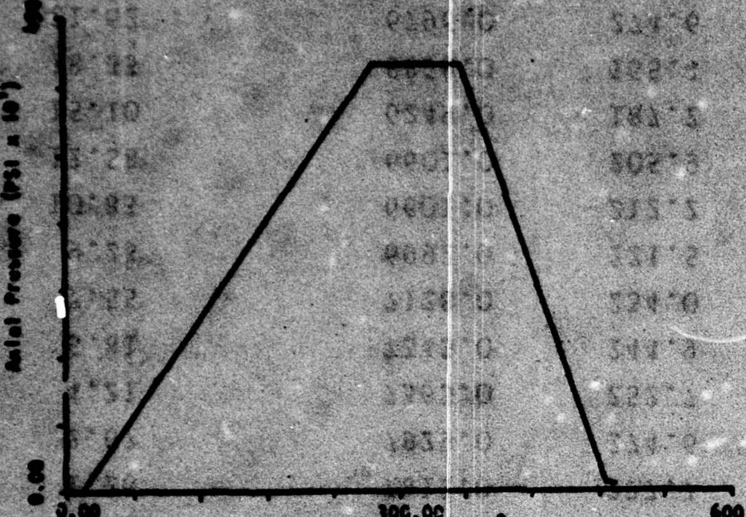
Pore pressure pipe had to be bled during initial loading period due to blocking up with sediment.

TABLE 7.10

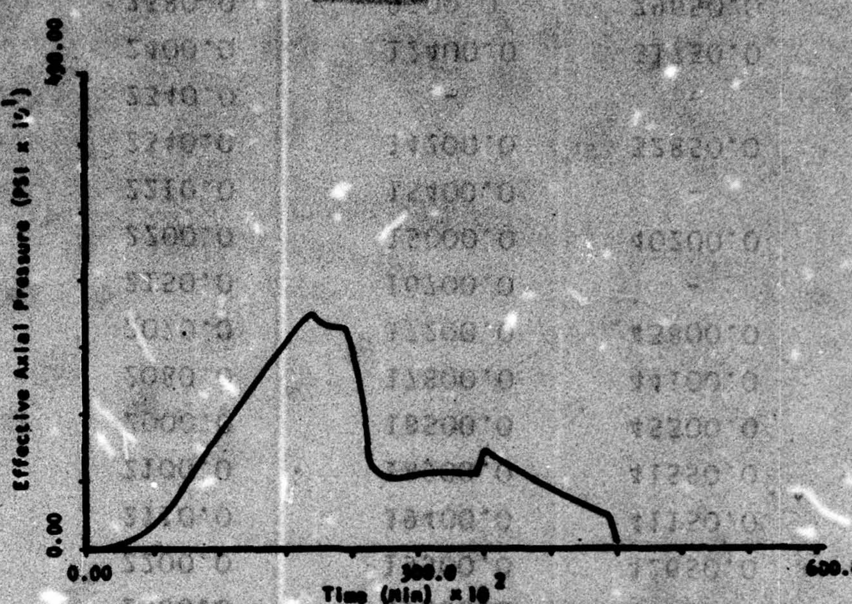
Results of chemical analysis of pore fluids expelled from FE 29

Axial Pressure MN/m^2	Concentration mg/1 Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
0.04	7812.0	290.2	2855.0	819.0	1860.0	20000.0	39650.0
0.10	7695.0	287.0	3089.0	787.8	1880.0	19600.0	39800.0
0.17	7714.0	280.8	2870.0	787.8	1900.0	19800.0	41450.0
0.28	7695.0	280.8	3026.0	795.6	1960.0	19800.0	42350.0
0.32	7636.0	279.2	2886.0	787.8	2000.0	19700.0	40850.0
0.36	7792.0	282.4	2964.0	787.8	2000.0	19600.0	41400.0
0.45	7812.0	282.4	2902.0	787.8	2080.0	19600.0	41200.0
0.52	7792.0	274.6	2746.0	787.8	2200.0	19600.0	41750.0
0.60	7148.0	255.8	2465.0	741.0	1860.0	19500.0	37600.0
1.26	7812.0	277.7	2527.0	795.6	2200.0	19500.0	42650.0
2.67	7929.0	274.6	2590.0	826.8	2110.0	19400.0	41150.0
4.21	7363.0	252.7	2434.0	795.6	2100.0	18900.0	41550.0
5.81	7343.0	244.9	2527.0	826.8	2000.0	18500.0	45300.0
7.55	7128.0	234.0	2402.0	795.6	2080.0	17800.0	44100.0
9.23	6992.0	221.5	2402.0	795.6	2070.0	17200.0	43800.0
10.83	6601.0	212.2	2215.0	780.0	2150.0	16700.0	-
12.58	6601.0	205.9	2184.0	764.4	2200.0	15000.0	40200.0
15.10	6249.0	187.2	2028.0	733.2	2210.0	15400.0	-
18.33	5898.0	165.4	1825.0	670.8	2340.0	14200.0	32850.0
21.62	6796.0	274.6	1934.0	748.8	2340.0	-	-
26.86	5351.0	137.3	1622.0	608.4	2400.0	12400.0	31750.0
30.67	4824.0	115.4	1373.0	546.0	2380.0	9700.0	29650.0

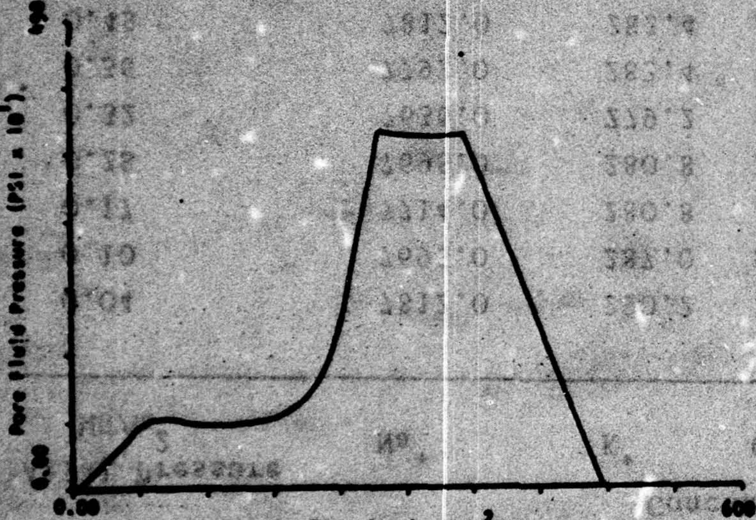
Test FE 29



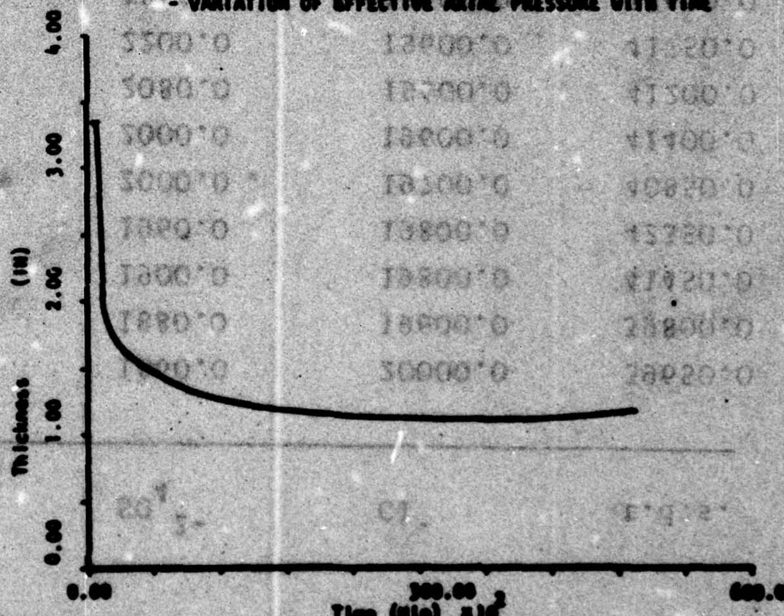
- VARIATION OF AXIAL PRESSURE WITH TIME



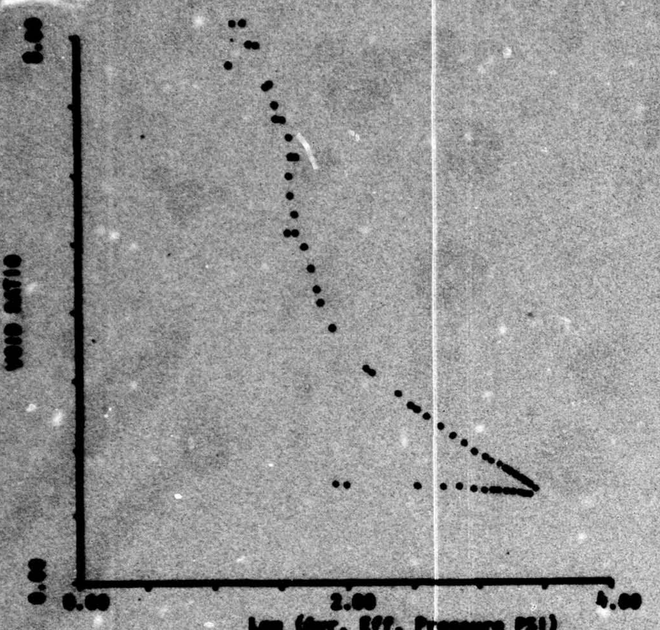
- VARIATION OF EFFECTIVE AXIAL PRESSURE WITH TIME



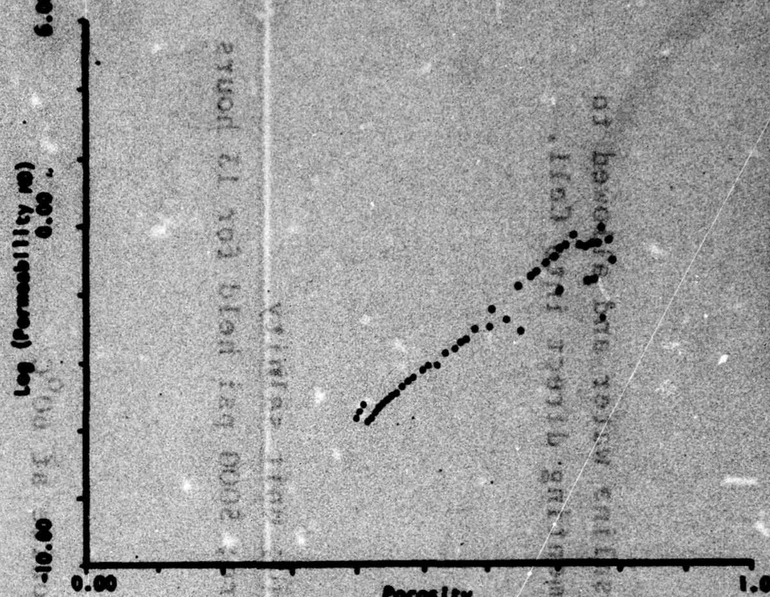
- VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME



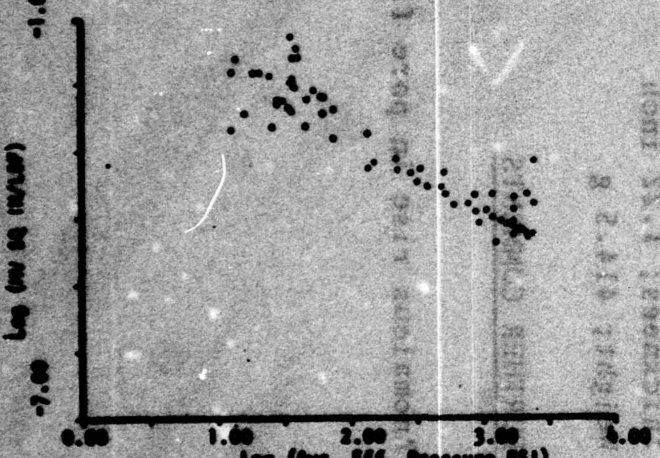
- CHANGE IN THICKNESS OF THE SAMPLE WITH TIME



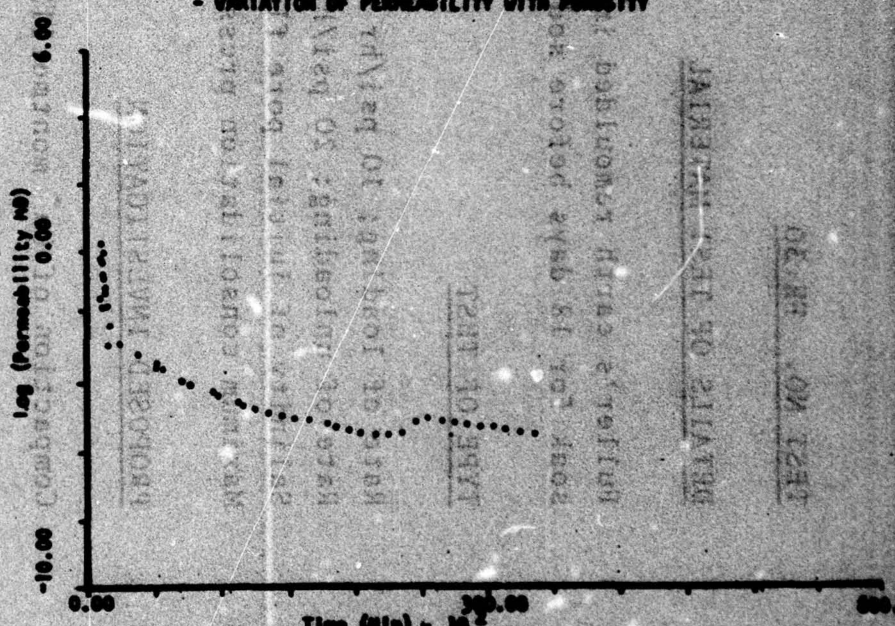
VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE



- VARIATION OF PERMEABILITY WITH POROSITY



- VARIATION OF COEFF. OF VOLUME DECREASE WITH EFFECTIVE PRESSURE



- VARIATION OF PERMEABILITY WITH TIME

TEST NO. FE 30 **Date: 26.3.76**

DETAILS OF TEST MATERIAL

Fuller's earth remoulded in saline water and allowed to soak for 18 days before sedimenting direct into Cell.

TYPE OF TEST

Rate of loading; 10 psi/hr
Rate of unloading; 20 psi/hr
Salinity of initial pore fluid; unit salinity
Maximum consolidation pressure; 5000 psi held for 13 hours

PROPOSED INVESTIGATION

Compaction of Ca⁻ montmorillonite at 60°C

INITIAL CONDITION OF SAMPLE

Thickness; 3.348 inches
Air dry weight; 392.0 g

FINAL CONDITION OF SAMPLE

Moisture content; 25.1 per cent
Thicknees; 1.22 inch
Weight; 414.5 g

FURTHER COMMENTS

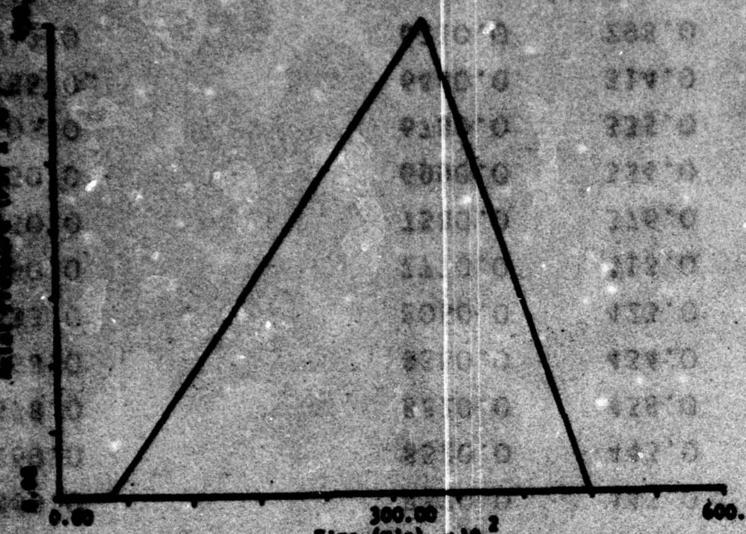
Anomalous rise in pore fluid.

TABLE 7.11

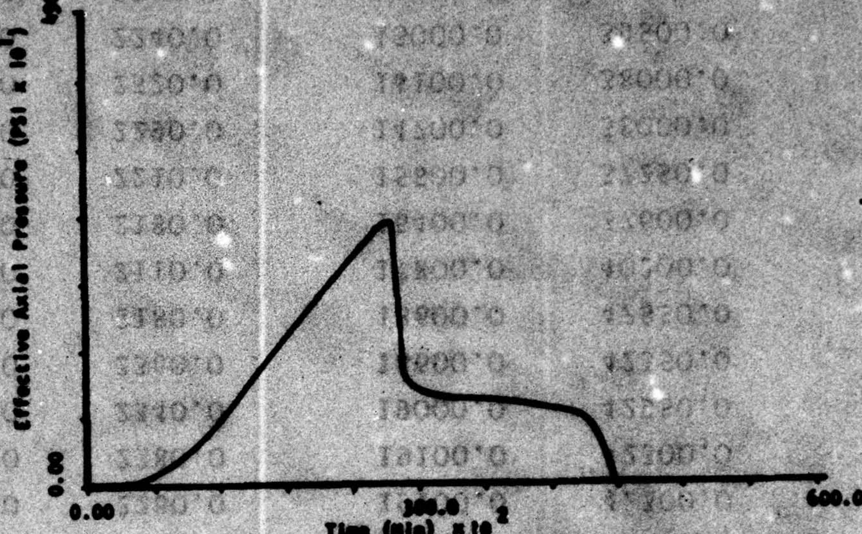
Results of chemical analysis of pore fluids expelled from FE 30

...ial Pressure (lbf/in^2)	Concentration mg/1 Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
2.0	9200.0	480.0	2400.0	889.0	2430.0	19000.0	38900.0
3.0	8570.0	480.0	2400.0	842.0	2540.0	19000.0	40500.0
5.0	8180.0	474.0	2400.0	913.0	2580.0	19100.0	40950.0
10.0	8750.0	471.0	2360.0	905.0	2540.0	18400.0	40650.0
10.0	8460.0	465.0	2340.0	858.0	2560.0	19100.0	40050.0
15.0	8200.0	456.0	2360.0	842.0	2432.0	19200.0	40800.0
20.0	8320.0	465.0	2400.0	888.0	2520.0	19400.0	41250.0
35.0	8200.0	465.0	2340.0	903.0	2580.0	19400.0	40700.0
45.0	8320.0	465.0	2400.0	905.0	2490.0	19400.0	41250.0
55.0	8440.0	460.0	2434.0	905.0	2380.0	19400.0	42150.0
67.0	8460.0	463.0	2480.0	920.0	2420.0	19500.0	42100.0
84.0	8340.0	460.0	2480.0	889.0	2360.0	19300.0	42950.0
172.0	8440.0	459.0	2480.0	920.0	2400.0	19300.0	43200.0
269.0	8320.0	443.0	2480.0	889.0	2280.0	19100.0	42300.0
269.0	8320.0	443.0	2480.0	889.0	2280.0	19100.0	42300.0
378.0	8220.0	438.0	2400.0	889.0	2340.0	19000.0	42950.0
558.0	8360.0	434.0	2400.0	874.0	2360.0	18600.0	42350.0
633.0	8050.0	423.0	2340.0	881.0	2180.0	18600.0	42850.0
890.0	7770.0	413.0	2280.0	874.0	2110.0	17800.0	40200.0
330.0	7380.0	376.0	2110.0	819.0	2180.0	16400.0	37600.0
830.0	6990.0	354.0	1950.0	803.0	2210.0	15500.0	37250.0
105.0	6780.0	335.0	1780.0	749.0	2290.0	14700.0	38000.0
486.00	6480.0	314.0	1720.0	694.0	2320.0	18100.0	38000.0
048.0	6210.0	298.0	1760.0	616.0	2240.0	13000.0	39500.0
668.0	5780.0	271.0	1450.0	577.0	2200.0	12000.0	28400.0
450.0	5600.0	248.0	1330.0	538.0	2160.0	11000.0	27600.0

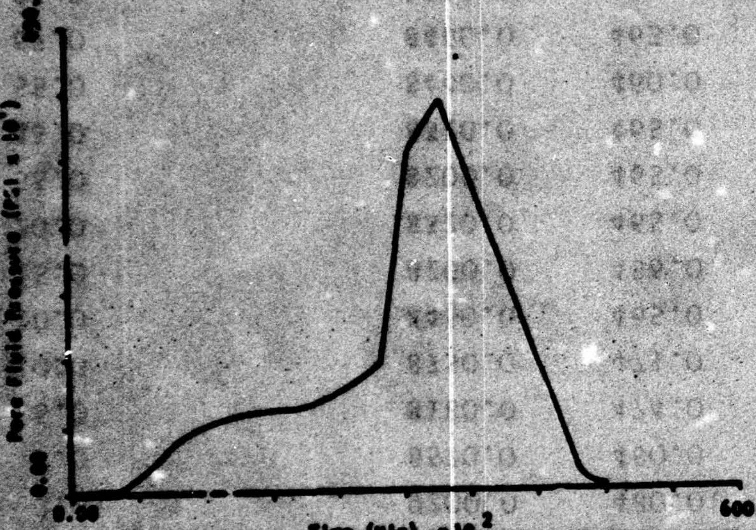
Test FE 33



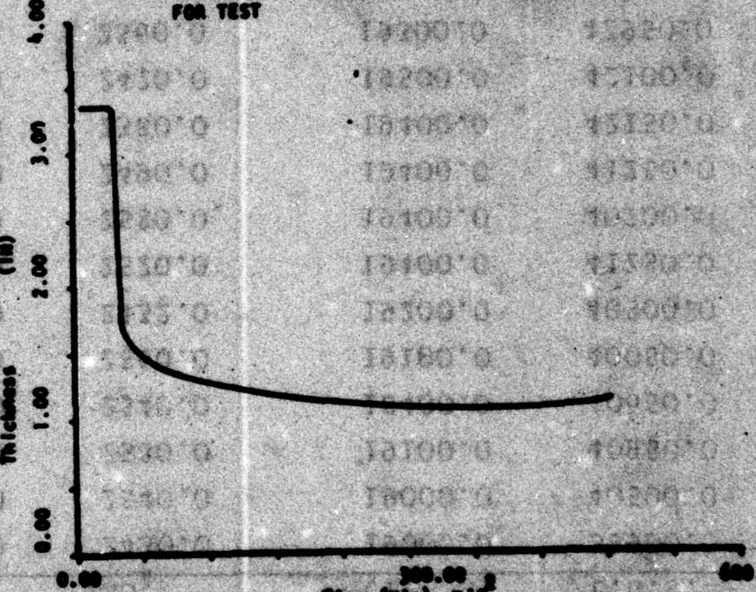
- VARIATION OF AXIAL PRESSURE WITH TIME



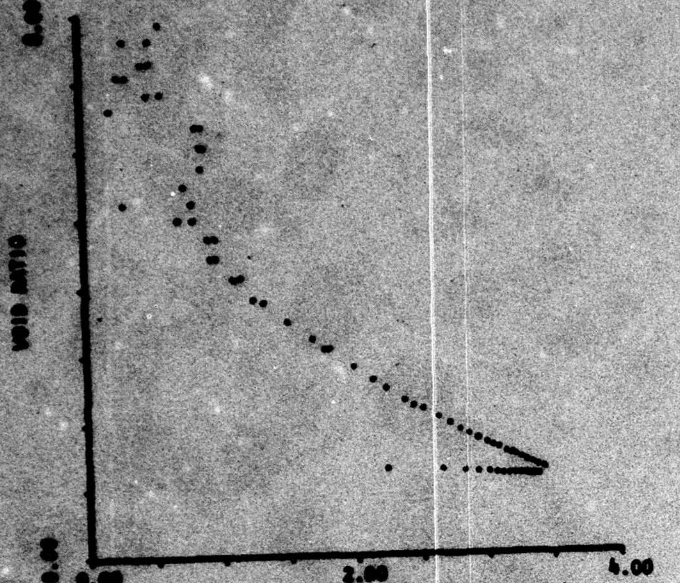
- VARIATION OF EFFECTIVE AXIAL PRESSURE WITH TIME FOR TEST



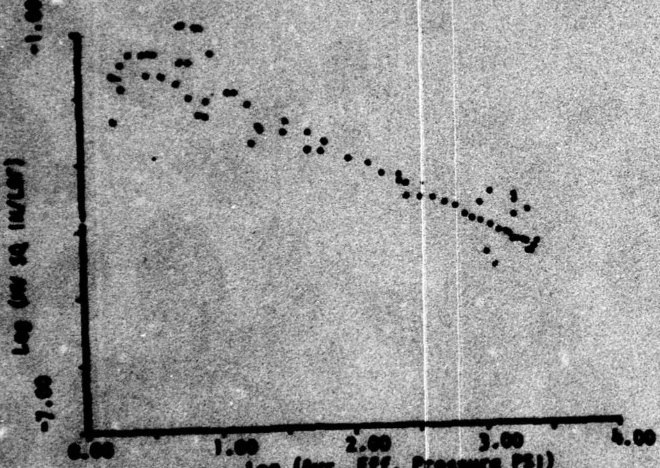
- VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME



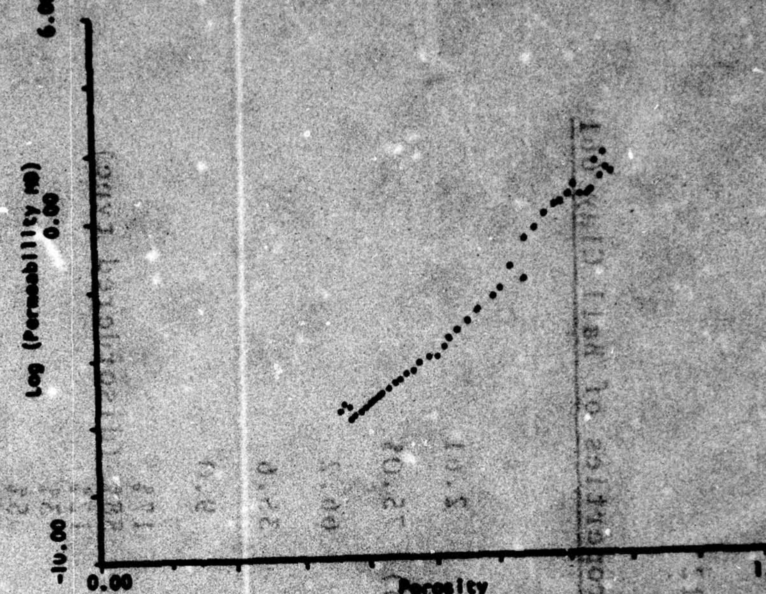
- CHANGE IN THICKNESS OF THE SAMPLE WITH TIME



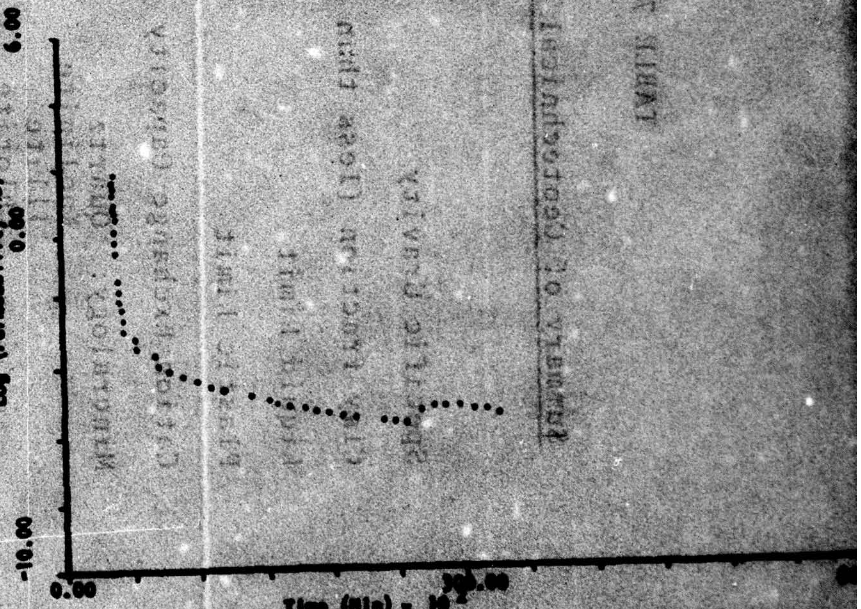
VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE



- VARIATION OF COEFF. OF VOLUME DECREASE WITH EFFECTIVE PRESSURE



- VARIATION OF PERMEABILITY WITH POROSITY



- VARIATION OF PERMEABILITY WITH TIME

TABLE 7.12

Summary of Geotechnical Properties of Ball Clay 661

Specific Gravity	2.61	
Clay fraction (less than 2μ)	75.0%	
Liquid Limit	66.2	
Plastic Limit	35.6	
Cation Exchange Capacity	9.0	
Mineralogy: Quartz	17%	
Kaolinite	58%	(disordered type)
Illite	12%	
Chlorite	3%	
Mixed Layer Minerals	5%	
Other Non-Clay Minerals	5%	

This material was used in the BC CHP Series of tests as described in the following pages and Test N BC CHP 1.

TEST NO. BC CHP 12 Date: 15.2.73

DETAILS OF TEST MATERIAL

Clay type; Ball clay; properties are in Table 7.12
State of original sample; remoulded with distilled water

TYPE OF TEST

Rate of loading; 1 psi per minute
Salinity of the pore fluid initially; non saline
Maximum consolidating pressure; 2,500 psi

PROPOSED INVESTIGATION

To investigate the influence of a time dependent increase in axial pressure on the consolidation behaviour of the clay.

INITIAL CONDITION OF THE SAMPLE

Moisture Content; 102.5 per cent
Thickness; 3.780 inches
Weight; 2.621 lbf

PRECONSOLIDATION STAGE

The specimen was not preconsolidated

LOADING STAGE

Total decrease in thickness; 1.455 inches
Equivalent change in Void ratio; 1.155

UNLOADING STAGE

Rate of unloading; 2 psi per minute
Total rebound of the sample; 0.179 inches

FINAL CONDITION OF THE SAMPLE

Moisture content; 20.7
Thickness; 1.902 inches
Weight; 2.183 lbf

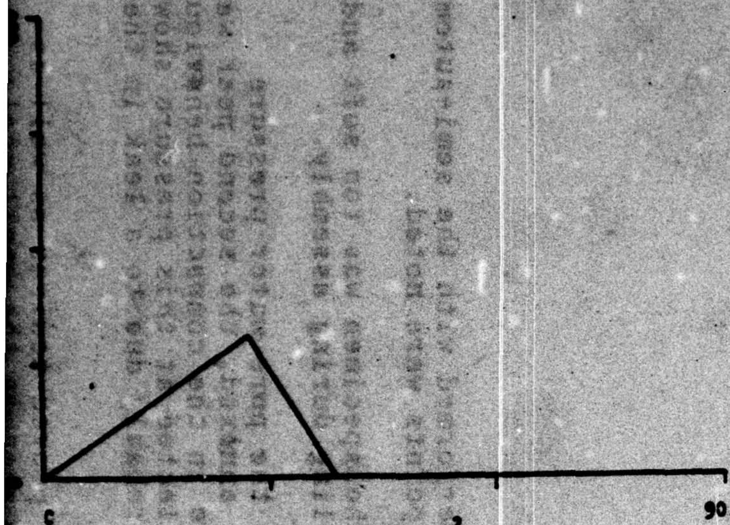
FURTHER COMMENTS

This test was the first to be performed with the semi-automatic loading system. The following points were noted:

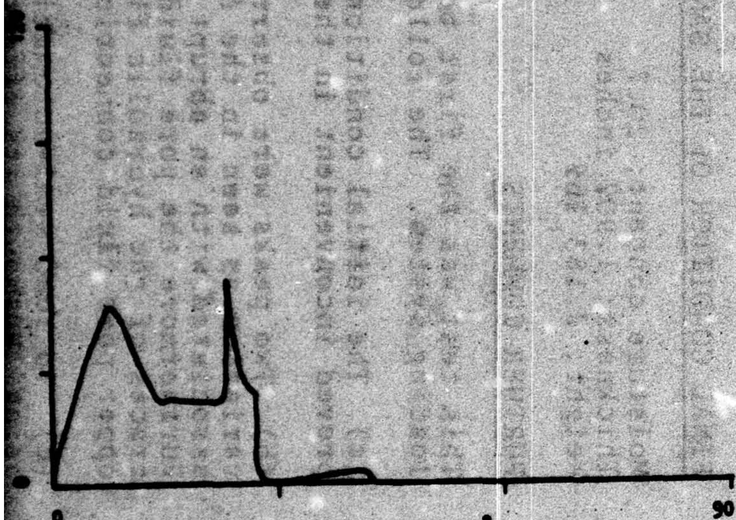
(a) The initial condition of the specimen was too soft and proved inconvenient in the handling during assembly.

(b) Two peaks were observed in the pore water pressure variation as seen in the figure annexed, the second peak was associated with an abrupt change in the compaction behaviour. Furthermore the pore fluids collected at this pressure showed traces of the hydraulic fluid probably due to a leak in the upper pore fluid connections.

(c) To load semi-automatically proved tedious as well as being unsmooth its effects are seen in the small scale

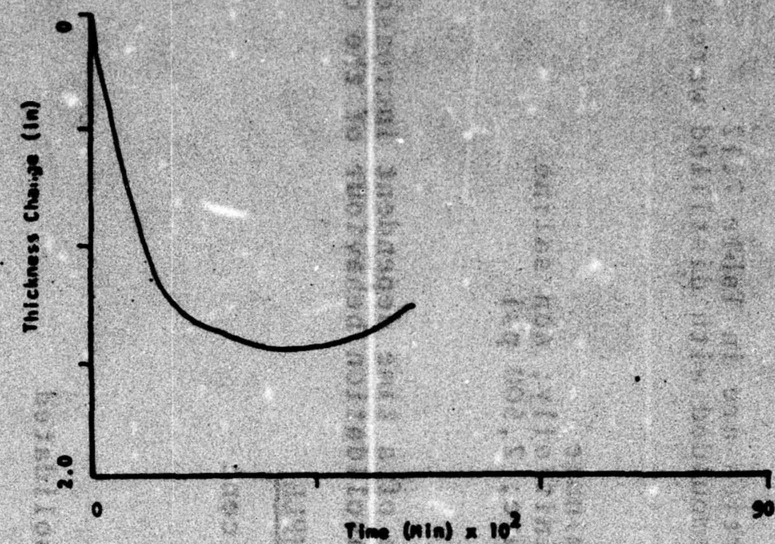


VARIATION OF AXIAL PRESSURE WITH TIME

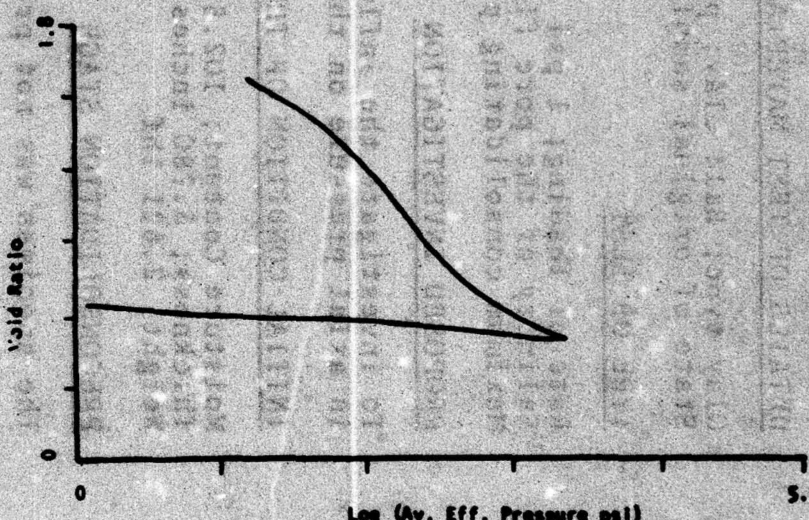


VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME

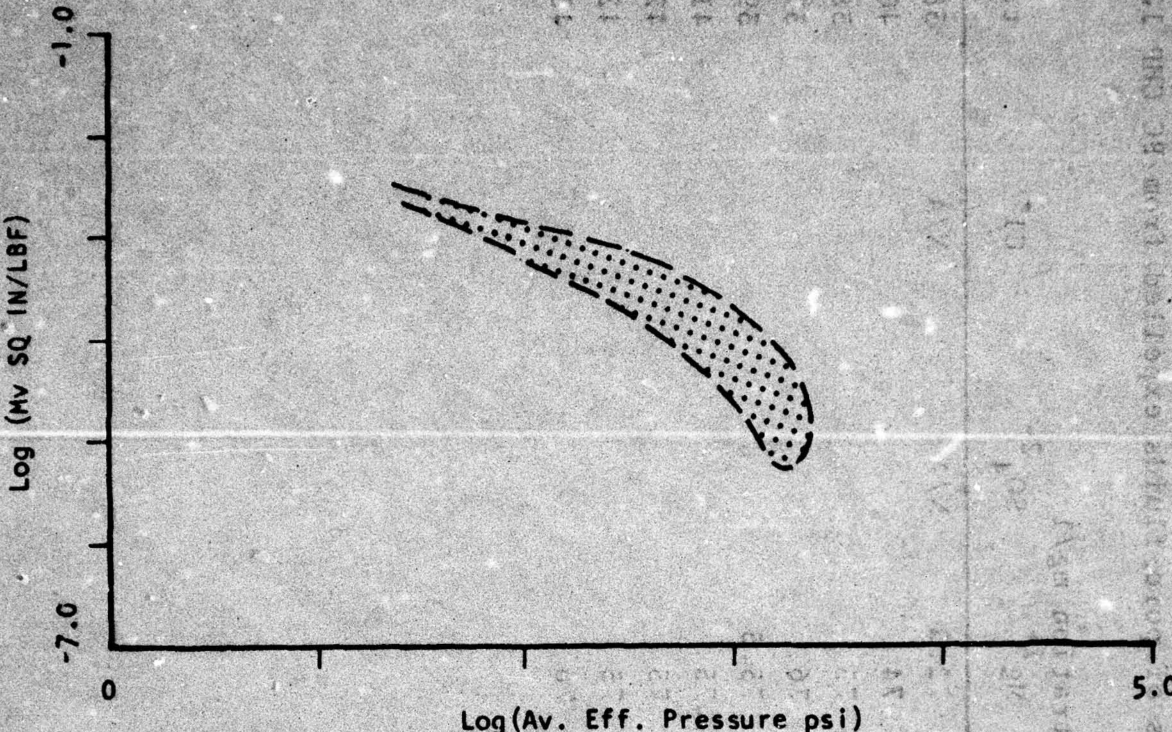
BC CHP 12



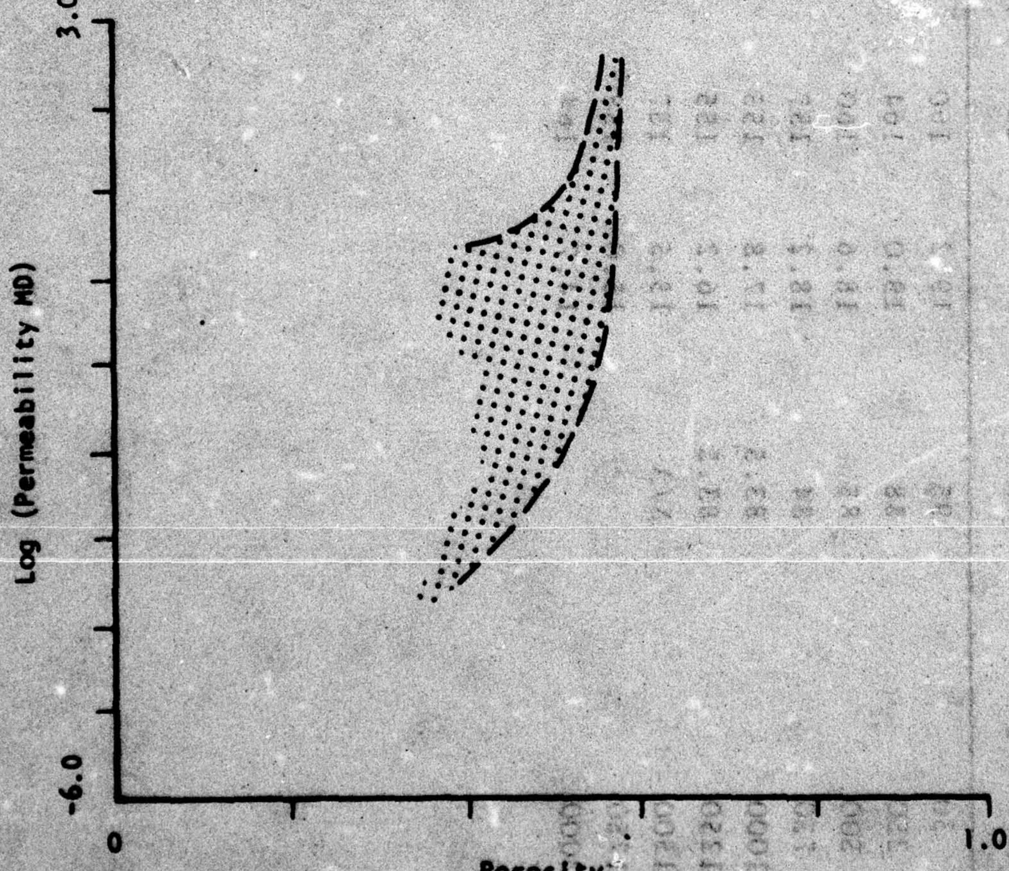
CHANGE IN THICKNESS OF SAMPLE WITH TIME



VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE



VARIATION OF COEFF. OF VOLUME DECREASE WITH EFFECTIVE PRESSURE



VARIATION OF PERMEABILITY WITH POROSITY

TABLE 7.13

Results of chemical analysis of pore fluids expelled from BC CHP 12

Axial Pressure (lbf/in^2)	Concentration mg/1						
	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
50	95	19.2	160	72.5	N/A	N/A	3800
250	88	19.0	164	74			4000
500	85	18.6	160	75			3800
750	84	18.2	157	76			3750
1000	83.5	17.8	155	75.5			3950
1250	83.5	16.2	155	75			4100
1500	N/A	15.5	157	75			4200
1750		15.0	158	75			4250
2000		14.7	164	76			4350

TEST NO. BC CHP 14 Date: 8.3.73

DETAILS OF TEST MATERIAL

Clay type; Ball clay; properties are in Table 7.12
State of original sample; remoulded with distilled water

TYPE OF TEST

Rate of loading; 1 psi/min
Salinity of the pore fluid initially; non saline
Maximum consolidation pressure; 4653 psi

PROPOSED INVESTIGATION

To study the repeatability of the experiment and also to observe the effects of preconsolidation.

INITIAL CONDITION OF THE SAMPLE

Moisture Content; 101.5 per cent
Thickness; 5.875 inches
Weight; 3.918 lbf

PRECONSOLIDATION STAGE

Rate of strain; 0.0017 inches/min deformation
Maximum preconsolidation stress; 84 psi
Moisture content after preconsolidation; 56.70 (computed)
Thickness after preconsolidation; 3.970 inches
Weight after preconsolidation; 3.021 lbf

LOADING STAGE

Total decrease in thickness; 1.514 inches
Equivalent change in void ratio; 1.005

UNLOADING STAGE

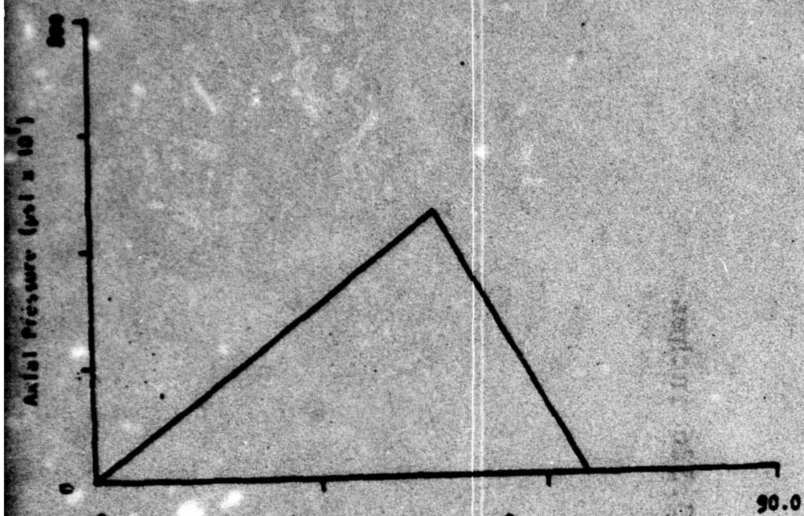
Rate of unloading; 2 psi/min
Total rebound of the sample; 0.326 inches

FINAL CONDITION OF THE SAMPLE

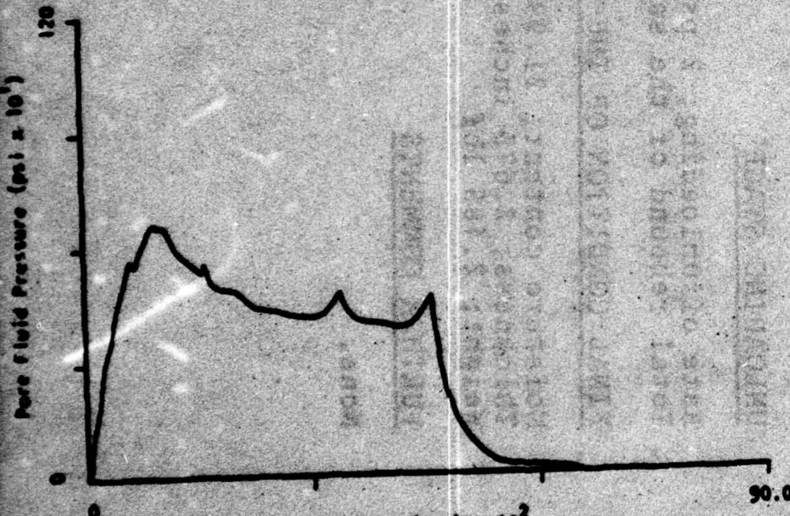
Moisture content; 21.99%
Thickness; 2.675 inches
Weight; 2.485 lbf

FURTHER COMMENTS

None.

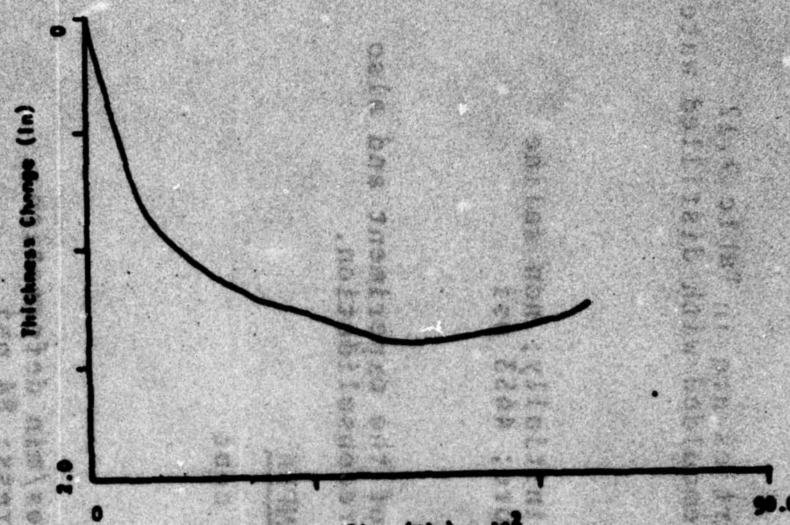


VARIATION OF AXIAL PRESSURE WITH TIME

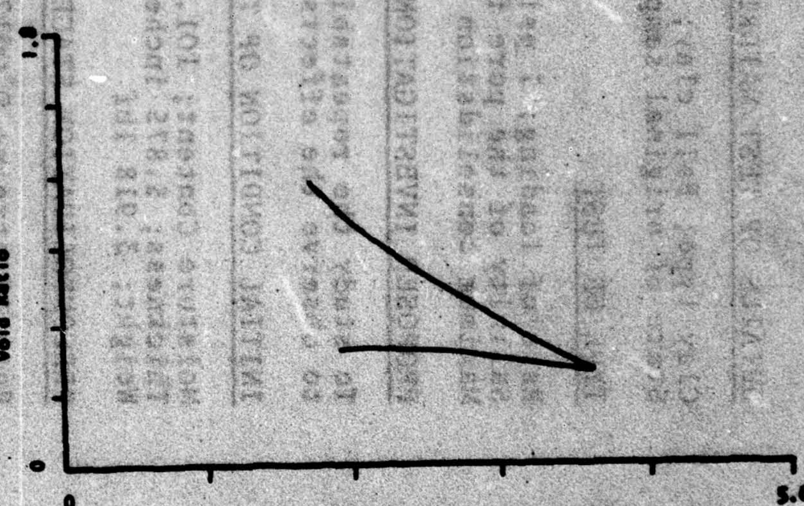


VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME

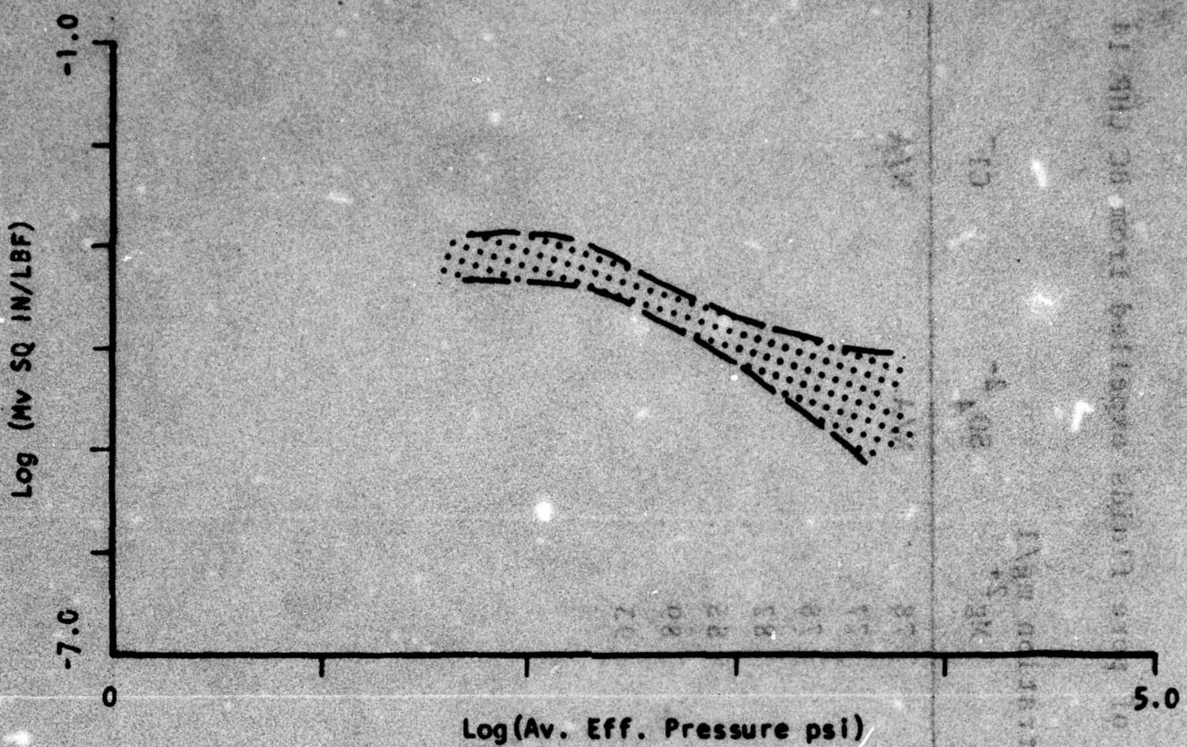
DC CHP 14



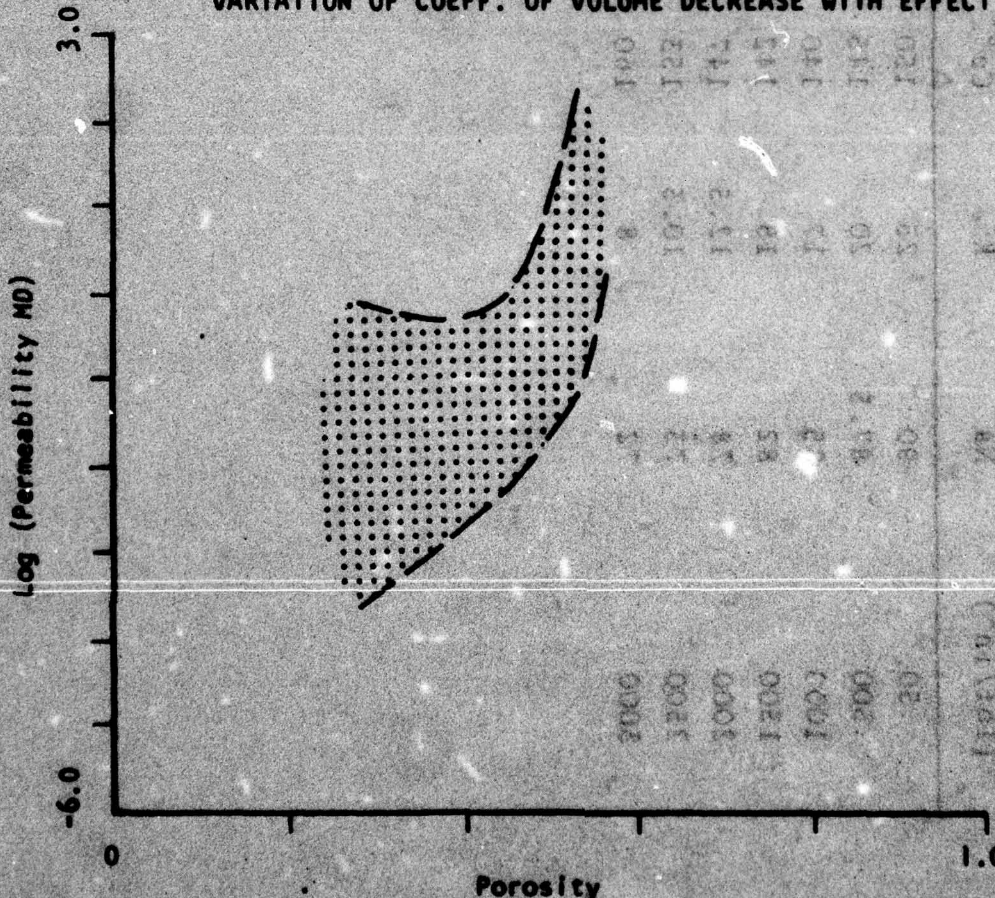
CHANGE IN THICKNESS OF SAMPLE WITH TIME



VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE



VARIATION OF COEFF. OF VOLUME DECREASE WITH EFFECTIVE PRESSURE



VARIATION OF PERMEABILITY WITH POROSITY

TABLE 7.14

Results of chemical analysis of pore fluids expelled from BC CHP 14

Axial Pressure (lbf/in^2)	Concentration mg/1 Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
50	90	25	150	78	N/A	N/A	4600
500	87.5	20	145	77			3500
1000	85	17	140	78			3750
1500	82	15	142	82			4250
2000	78	12.5	147	85			4500
2500	75	10.5	153	89			4800
3000	72	8	160	93			5250

TEST NO. BC CHP 15 **Date: 22.5.73**

DETAILS OF TEST MATERIAL

Clay type; Ball clay properties in Table 7.12
State of original sample; remoulded with half- normal saline water

TYPE OF TEST

Rate of loading; 1 psi per minute
Salinity of the pore fluid initially; half-normal saline
Maximum consolidating pressure; 7000 psi

PROPOSED INVESTIGATION

To investigate the influence of a saline pore fluid

INITIAL CONDITION OF THE SAMPLE

Moisture Content; 97.8 per cent
Thickness; 5.45 inches
Weight; 3.549 lbf

PRECONSOLIDATION STAGE

Rate of strain; 0.0017 inches per minute
Maximum preconsolidation stress; 85 psi
Moisture content after preconsolidation; 61.60 per cent
Thickness after preconsolidation; 3.437 inches
Weight after preconsolidation; 2.645 lbf

LOADING STAGE

Total decrease in thickness; 1.58 inches

UNLOADING STAGE

Total decrease in thickness; very rapid
Total rebound of the sample; could not be monitored

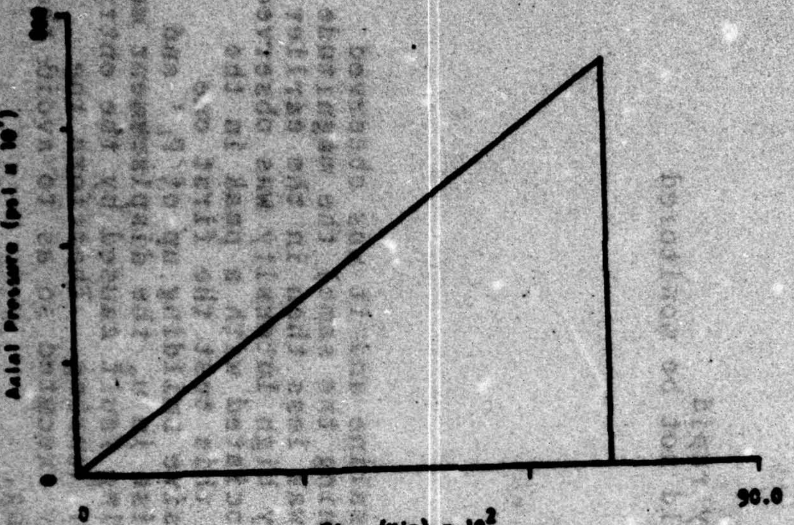
FINAL CONDITION OF THE SAMPLE

Moisture content; 11.75 per cent
Thickness; 2.210 inches
Weight; 2.05 lbf

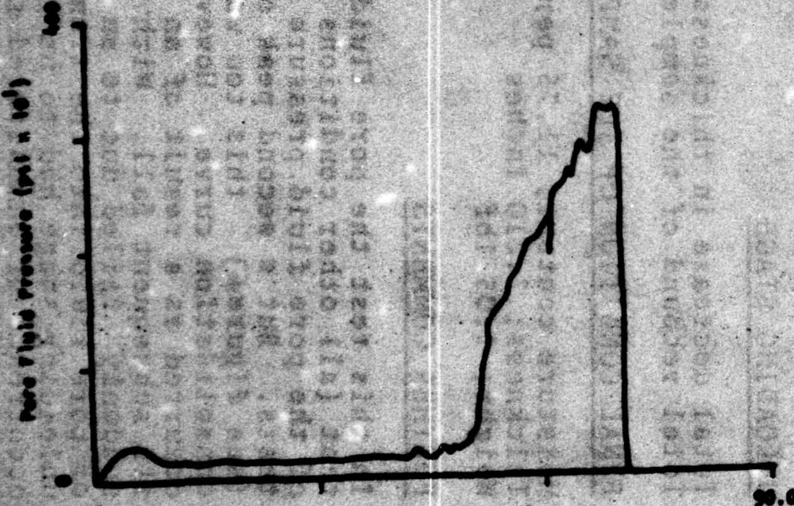
FURTHER COMMENTS

In this test the pore fluid was saline and it was observed that (all other conditions remaining the same) the magnitude of the pore fluid pressure peak was less than in the earlier tests. But a second peak of very high intensity was observed (see figures) this too was associated with a peak in the consolidation curve. However in this test the first one occurred as a result of an excessive building up of P_1' and its subsequent fall. With the rise in u, the displacement monitor suddenly failed due to an earthing fault caused by the entry of pore fluid into the transducer housing. Therefore the unloading stage had to be rapidly excepted so as to avoid the occurrence of unmonitored swelling.

EC CHP 15

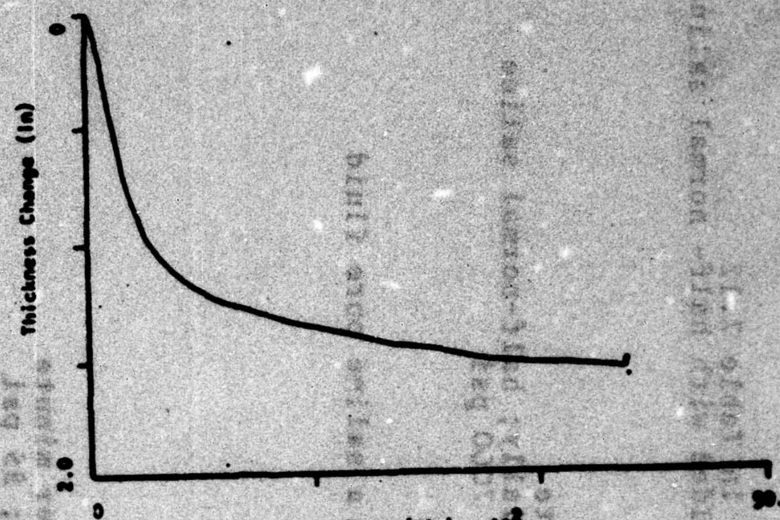


VARIATION OF AXIAL PRESSURE WITH TIME

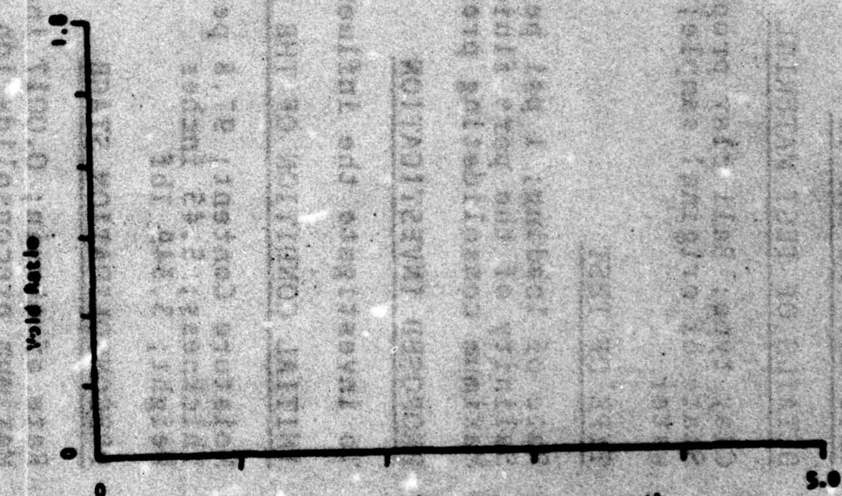


VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME

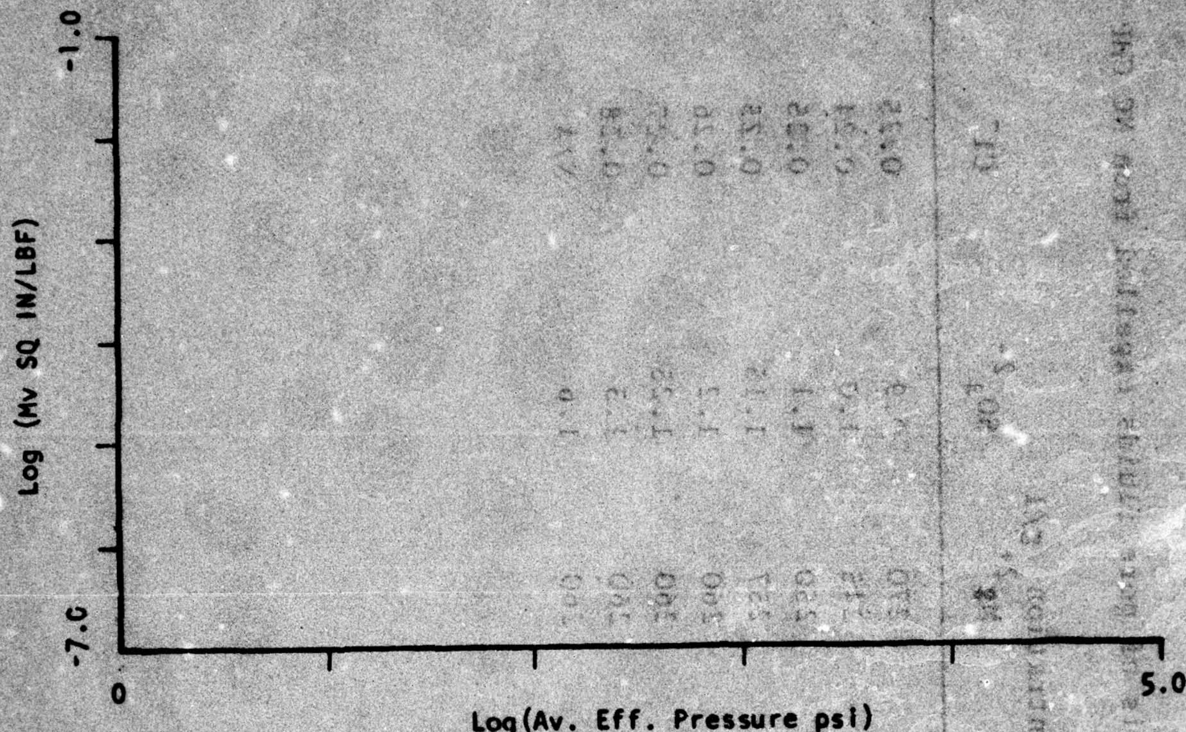
EC CHP 15



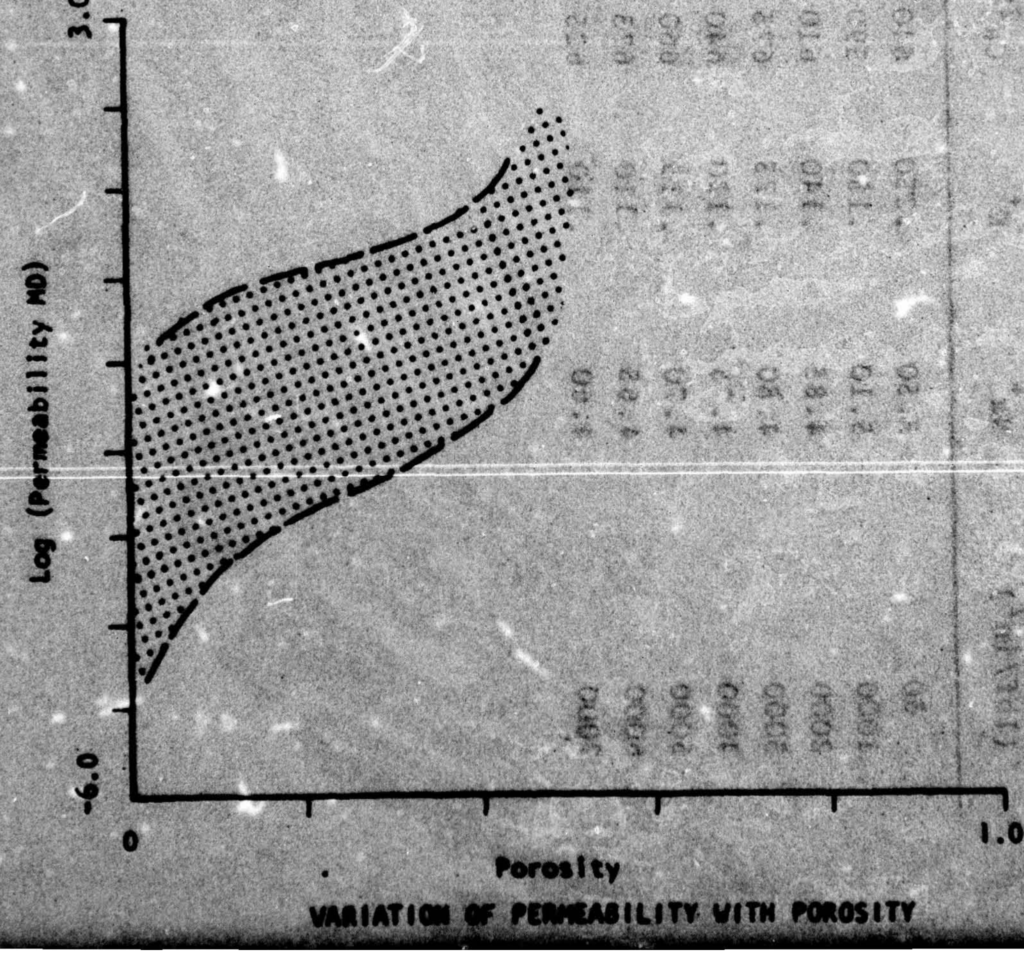
CHANGE IN THICKNESS OF SAMPLE WITH TIME



VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE



VARIATION OF COEFF. OF VOLUME DECREASE WITH EFFECTIVE PRESSURE



VARIATION OF PERMEABILITY WITH POROSITY

TABLE 7.15

Results of chemical analysis of pore fluids expelled from NC CHP 15

Axial Pressure (lbf/in^2)	Concentration g/l						
	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
50	5.50	.250	640	270	0.9	0.25	15
1000	5.10	.150	590	245	1.0	0.24	16
2000	4.85	.140	610	250	1.1	0.25	17.5
3000	4.80	.125	625	257	1.15	0.25	18.5
4000	4.75	.120	640	260	1.2	0.26	19
5000	4.70	.115	660	260	1.25	0.27	21
6000	4.65	.110	675	260	1.3	0.28	21.5
7000	4.60	.110	625	260	1.6	N/A	22

TEST NO. BC CHP 17 **Date: 2.7.75**

DETAILS OF TEST MATERIAL

Clay type; Ball clay properties as in Table 7.12
State of original sample; remoulded in saline water

TYPE OF TEST

Rate of loading; 1 psi per minute
Salinity of the pore fluid initially; unit salinity
Maximum consolidation pressure; 5520 psi

PROPOSED INVESTIGATION

The influence of an increased salinity on consolidation behaviour

INITIAL CONDITION OF THE SAMPLE

Moisture Content; 94.0 per cent
Thickness; 5.68 inches
Weight; 3.527 lbf

PRECONSOLIDATION STAGE

Rate of strain; 0.0016 inch/min
Maximum preconsolidation stress; 85 psi
Moisture content after preconsolidation; 64.80 per cent
Thickness after preconsolidation; 3.880 inches
Weight after preconsolidation; 2.734 lbf

LOADING STAGE

Total decrease in thickness; 1.335 inches

UNLOADING STAGE

Rate of Unloading; very rapid
Total rebound of the sample; not monitored

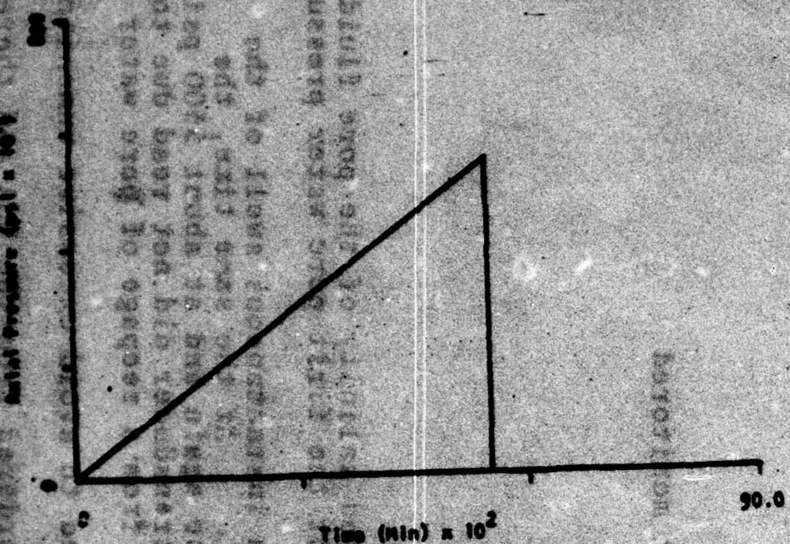
FINAL CONDITION OF THE SAMPLE

Moisture content; 13.36 per cent
Thickness; 2.3125 inches
Weight; 2.110 lbf

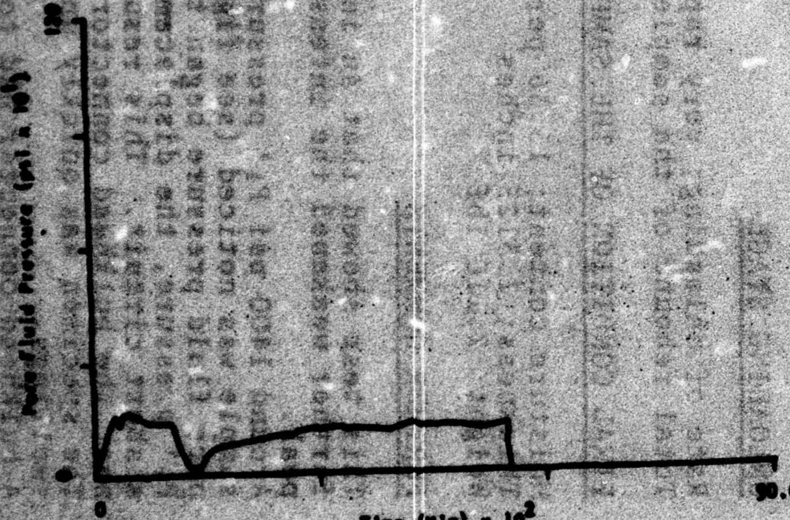
FURTHER COMMENTS

This test showed that an increased salinity of the pore fluid further weakened the intensity of the first pore water pressure peak.
Around 1400 psi P_1' pressure, an instantaneous swell of the sample was noticed (see figures). At the same time, the pore fluid pressure began to rise again and at about 5900 psi P_1' pressure, the displacement transducer did not read due to a short circuit. This resulted from a seepage of pore water near the bulkhead connector.
The specimen was quickly unloaded to avoid excessive unmonitored swellings.
A bulkhead connector had to be ordered from the USA and there was over 3 months delay.

BC CHP 17

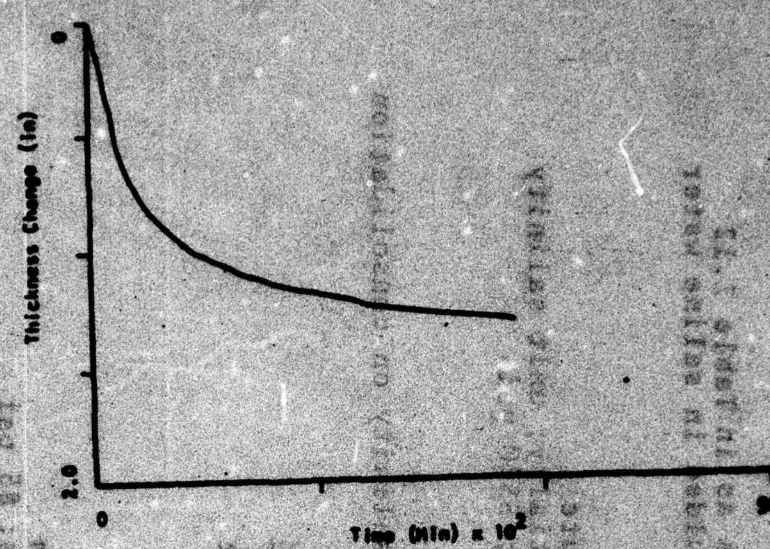


VARIATION OF AXIAL PRESSURE WITH TIME

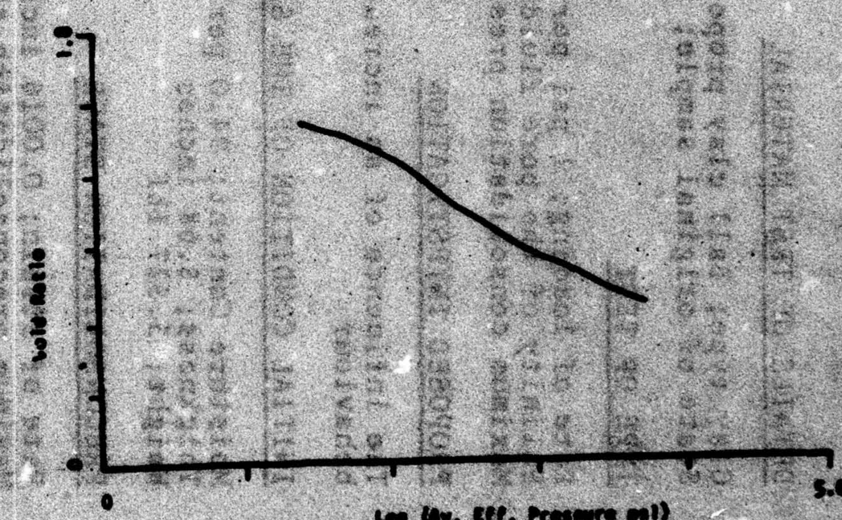


VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME

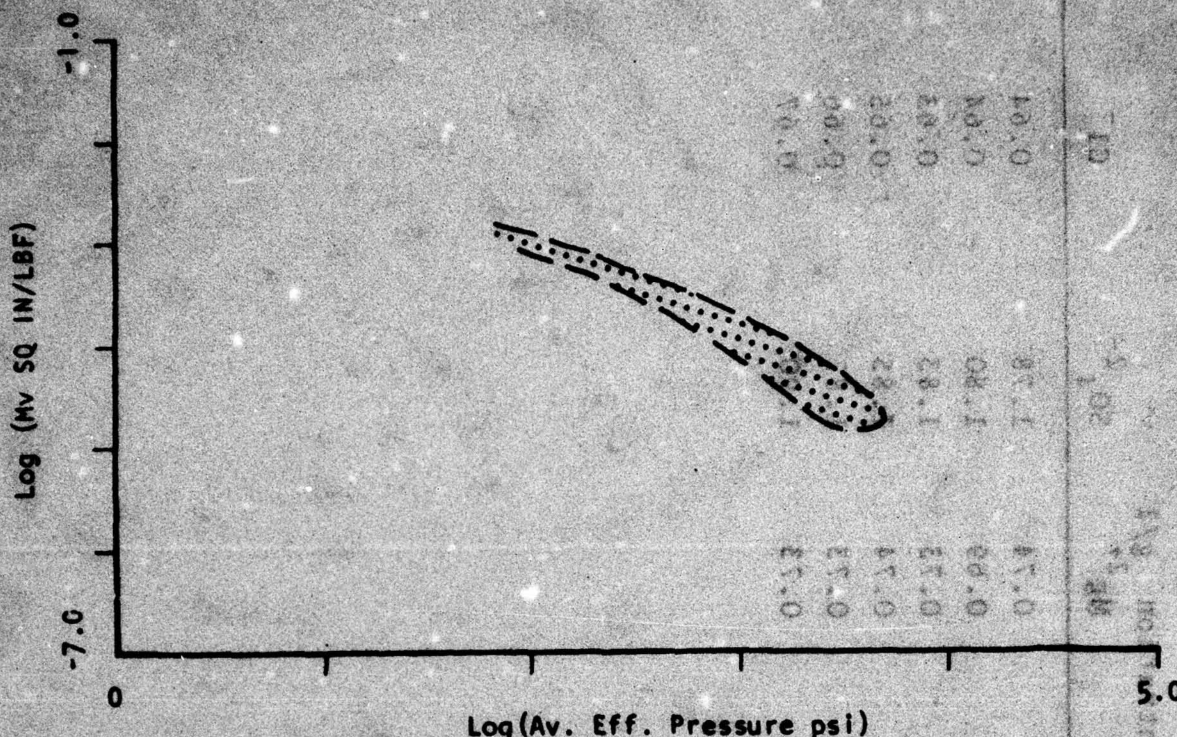
BC CHP 17



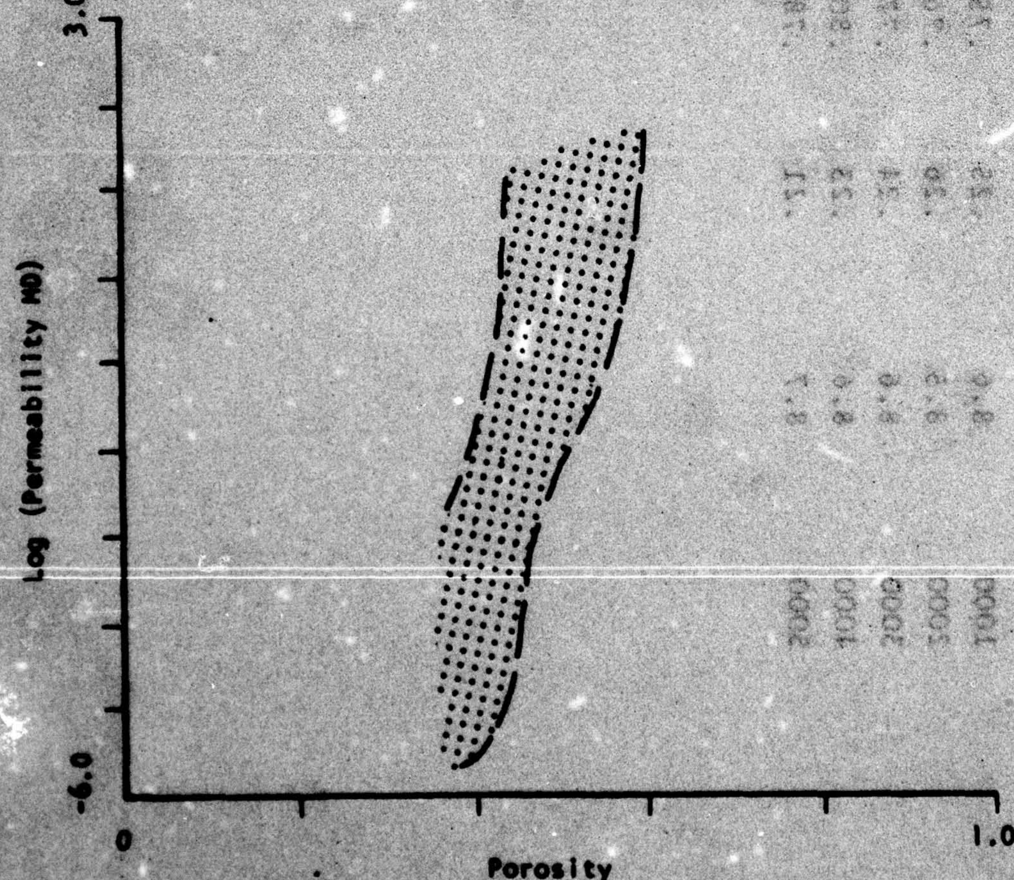
CHANGE IN THICKNESS OF SAMPLE WITH TIME



VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE



VARIATION OF COEFF. OF VOLUME DECREASE WITH EFFECTIVE PRESSURE



VARIATION OF PERMEABILITY WITH POROSITY

TABLE 7.16

Results of chemical analysis of pore fluids expelled from BC CHP 17

Axial Pressure (lbf/in^2)	Concentration g/1						
	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
50	10	.42	.775	0.74	1.78	0.64	31.0
1000	8.6	.25	.750	0.69	1.80	0.64	30.2
2000	8.5	.26	.760	0.73	1.83	0.63	30.[illegible]
3000	8.6	.24	.775	0.74	1.85	0.65	31.0
4000	8.6	.23	.800	0.73	1.87	0.66	31.0
5000	8.7	.21	.780	0.73	1.90	0.67	31.0

TEST NO. BC CHP 18 Date: 5.10.73

DETAILS OF TEST MATERIAL

Clay type; Ball clay properties as in Table 7.12
State of original sample; remoulded in distilled water

TYPE OF TEST

Rate of loading; 2 psi per minute
Salinity of the pore fluid initially; non saline
Maximum consolidating pressure; 5015 psi

PROPOSED INVESTIGATION

Second of a series of tests to investigate the effect of the rate of loading on the properties of the specimen

INITIAL CONDITION OF THE SAMPLE

Moisture Content; 86.0 per cent
Thickness; 5.775 inches
Weight;2.866 lbf

PRECONSOLIDATION STAGE

Rate of strain; 0.0017 inches/min
Maximum preconsolidation stress; 80 psi
Moisture content after preconsolidation; 61.0 per cent
Thickness after preconsolidation; 3.955 inches
Weight after preconsolidation; 2.381 lbf

LOADING STAGE

Total decrease in thickness; 1.5548 inches

UNLOADING STAGE

Rate of unloading; 2 psi per minute
Total rebound of the sample; 0.0906 inches

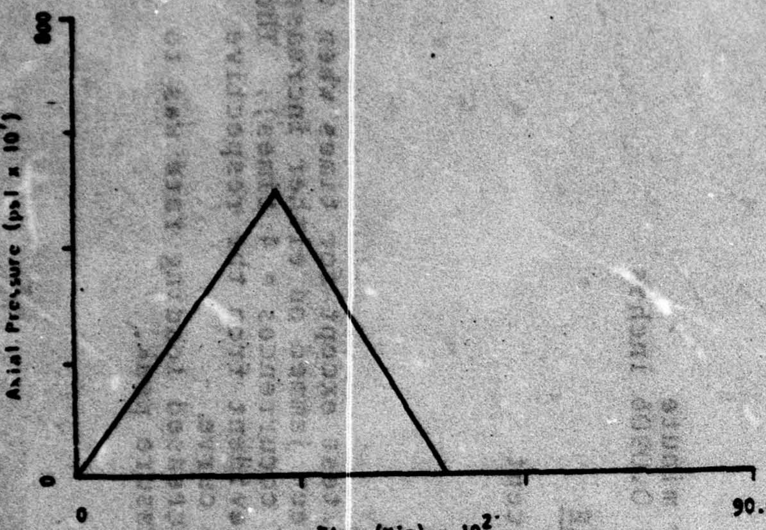
FINAL CONDITION OF THE SAMPLE

Moisture content; 16.36 per cent
Thickness; 2.3125 inches
Weight; 2.110 lbf

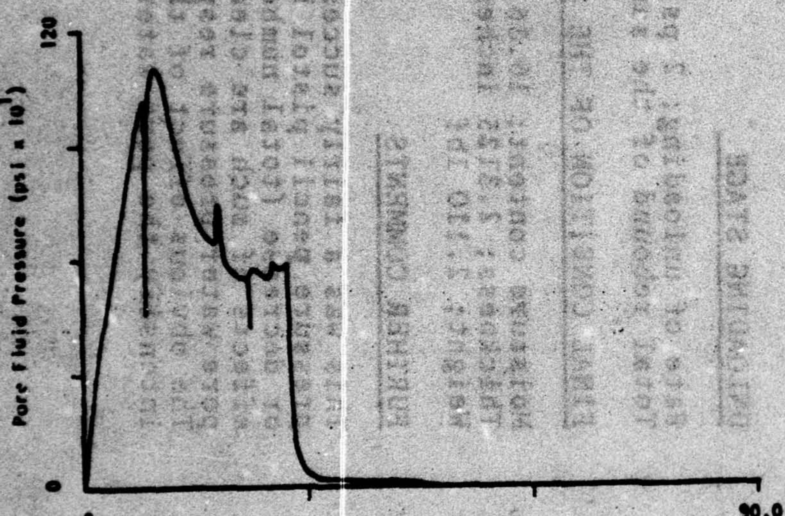
FURTHER COMMENTS

This was a fairly successful test except for times when the pressure pencil pistol had been jammed on either increase or decrease (total number of occurrences = 4 times). The effects of such are clearly evident from the respective pore water pressure response curve.
The obvious effect of the increased loading rate was to intensify the pore water pressure peak.

BC CHP 18

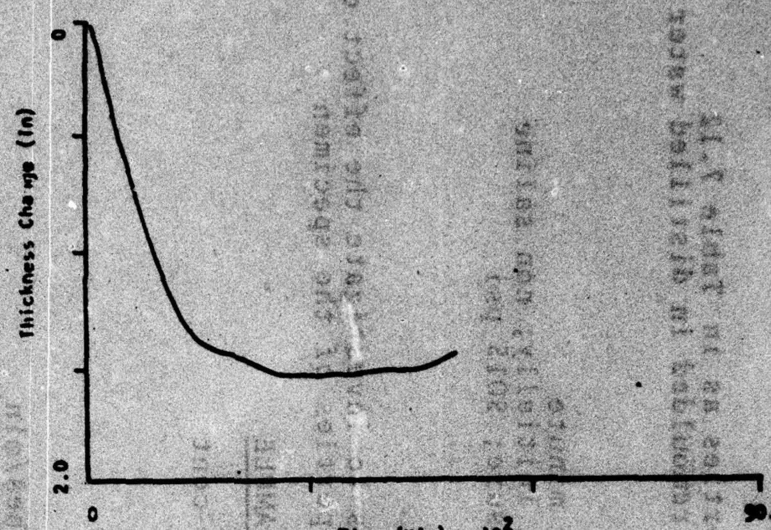


VARIATION OF AXIAL PRESSURE WITH TIME

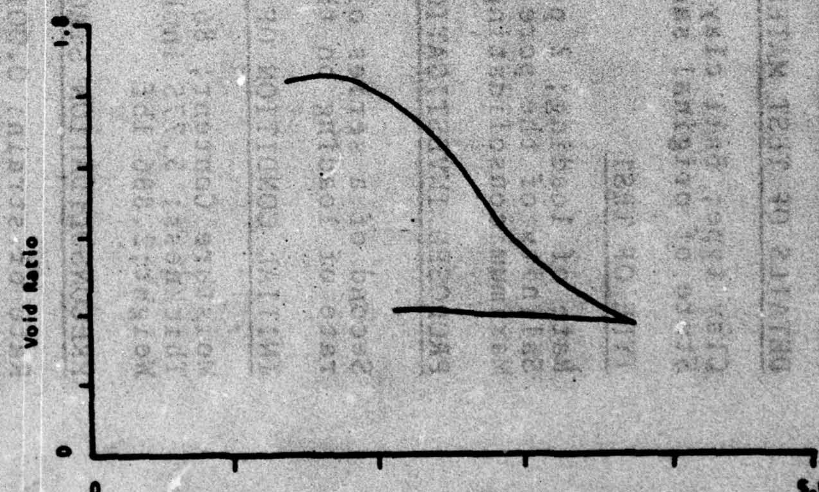


VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME

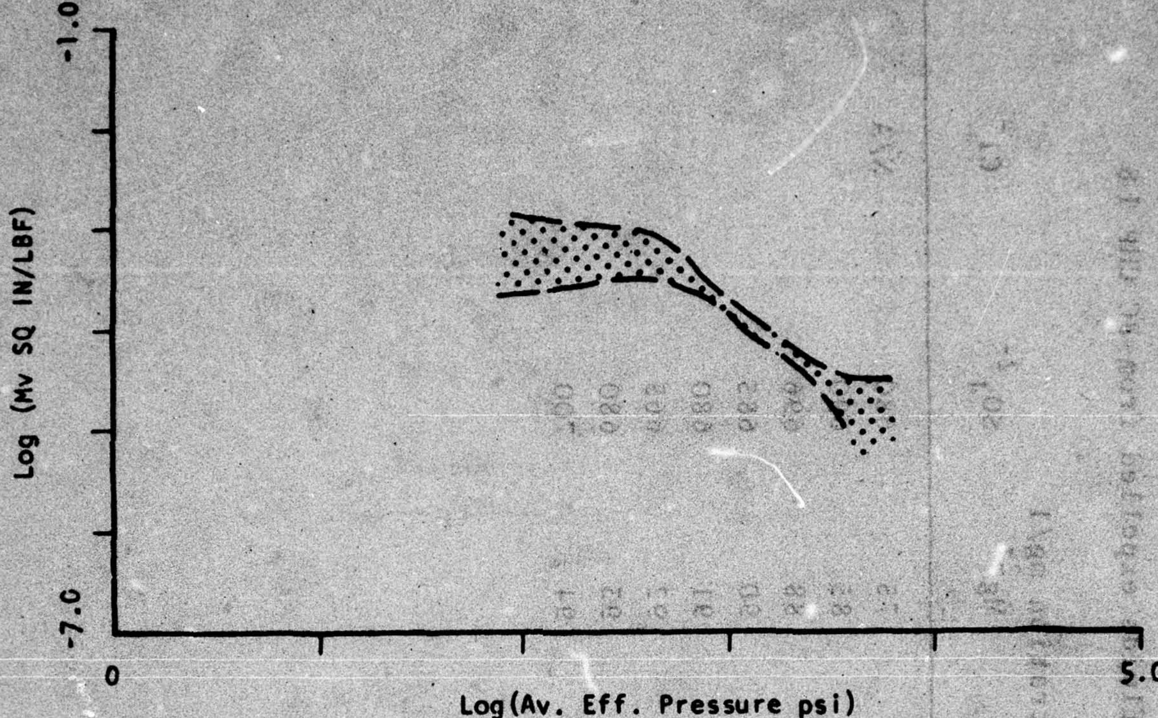
BC CHP 18



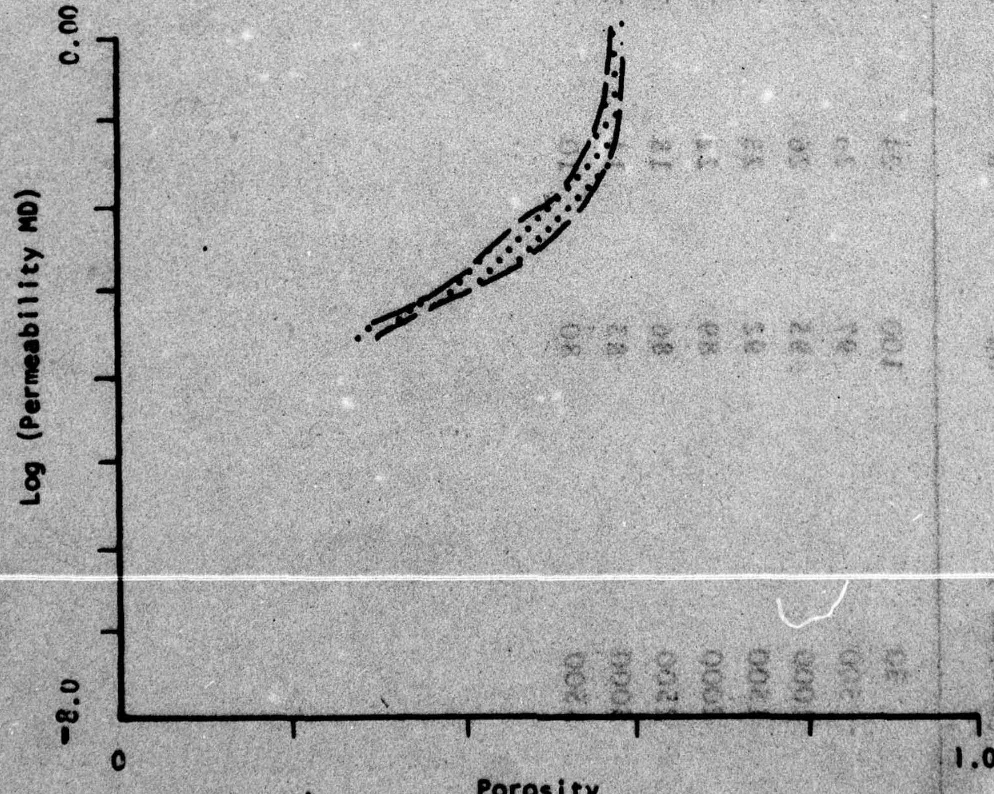
CHANGE IN THICKNESS OF SAMPLE WITH Time



VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE



VARIATION OF COEFF. OF VOLUME DECREASE WITH EFFECTIVE PRESSURE



VARIATION OF PERMEABILITY WITH POROSITY

TABLE 7.17

Results of chemical analysis of pore fluids expelled from BC CHP 18

Axial Pressure (lbf/in^2)	Concentration mg/1						
	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
50	100	24	7.1	75	680	N/A	1800
500	97	26	7.4	85	690		1750
1000	95	26	7.7	88	696		1500
1500	92	25	7.5	90	685		1300
2000	89	22	7.6	91	680		1800
2500	86	18	7.7	92	665		2500
3000	83	14	7.7	93	680		3000
3500	80	10	7.6	94	700		3400

TEST NO. ''BC CHP 19 **Date: 26.10.73**

DETAILS OF TEST MATERIAL

Clay type; Ball clay; properties as in Table 7.12
State of original sample; remoulded in distilled water

TYPE OF TEST

Rate of loading; ½ psi per minute
Salinity of the pore fluid initially; non saline
Maximum consolidation pressure; 6604 psi

PROPOSED INVESTIGATION

The third test of a series investigating the influence of rate of loading on the compaction behaviour.

INITIAL CONDITION OF THE SAMPLE

Moisture Content; 113.0 per cent
Thickness; 5.405 inches
Weight; 3.439 lbf

PRECONSOLIDATION STAGE

Rate of strain; 0.0017 inches per minute
Maximum preconsolidation stress; 85 psi
Moisture content after preconsolidation; 69.65
Thickness after preconsolidation; 3.655 inches
Weight after preconsolidation; 2.954 lbf

LOADING STAGE

Total decrease in thickness; 1.715 inches

UNLOADING STAGE

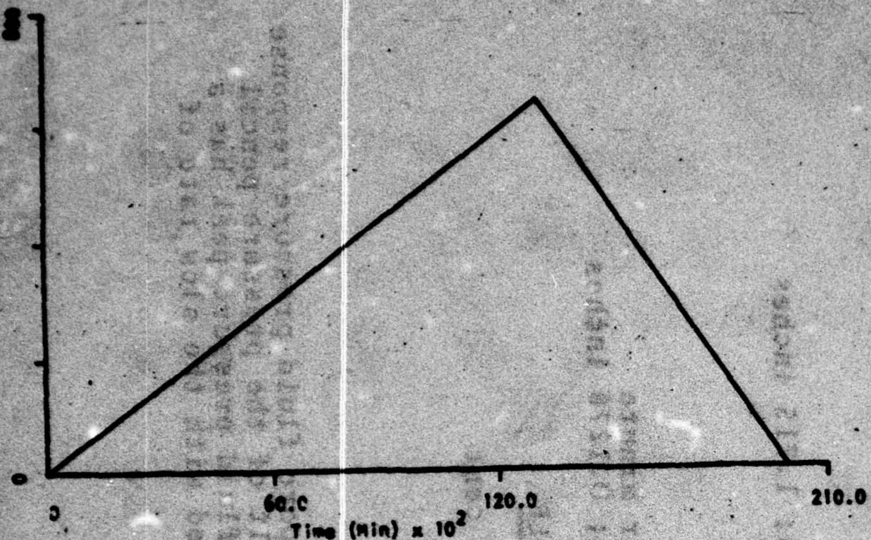
Rate of unloading; 2 psi per minute
Total rebound of the sample; 0.1278 inches

FINAL CONDITION OF THE SAMPLE

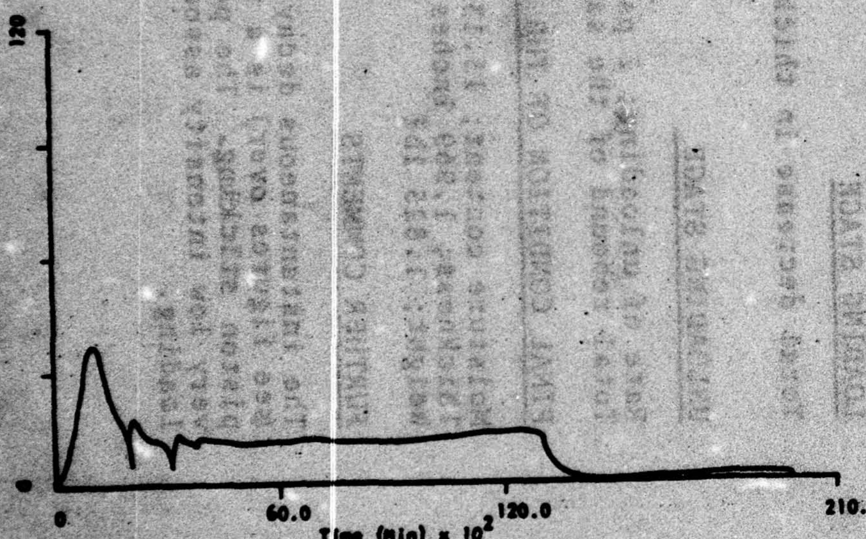
Moisture content; 13.13 per cent
Thickness; 1.969 inches
Weight; 1.825 lbf

FURTHER COMMENTS

The instantaneous decay of pore fluid pressure response (see figures over) is a result of the pressure pencil piston sticking. The pore fluid pressure peak has a very low intensity associated with the slow rate of loading.

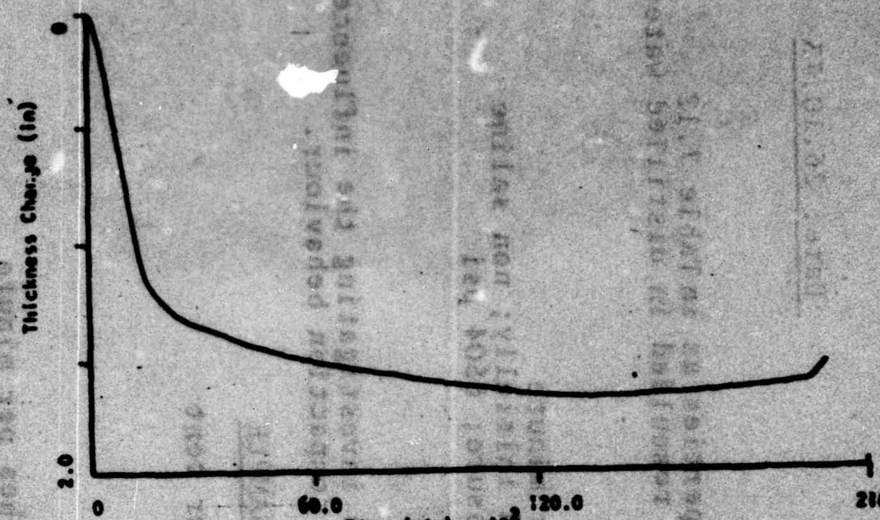


VARIATION OF AXIAL PRESSURE WITH TIME

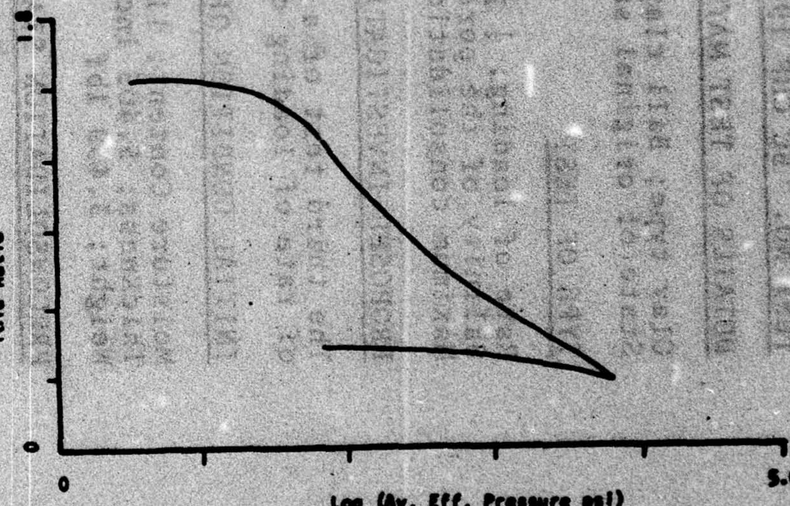


VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME

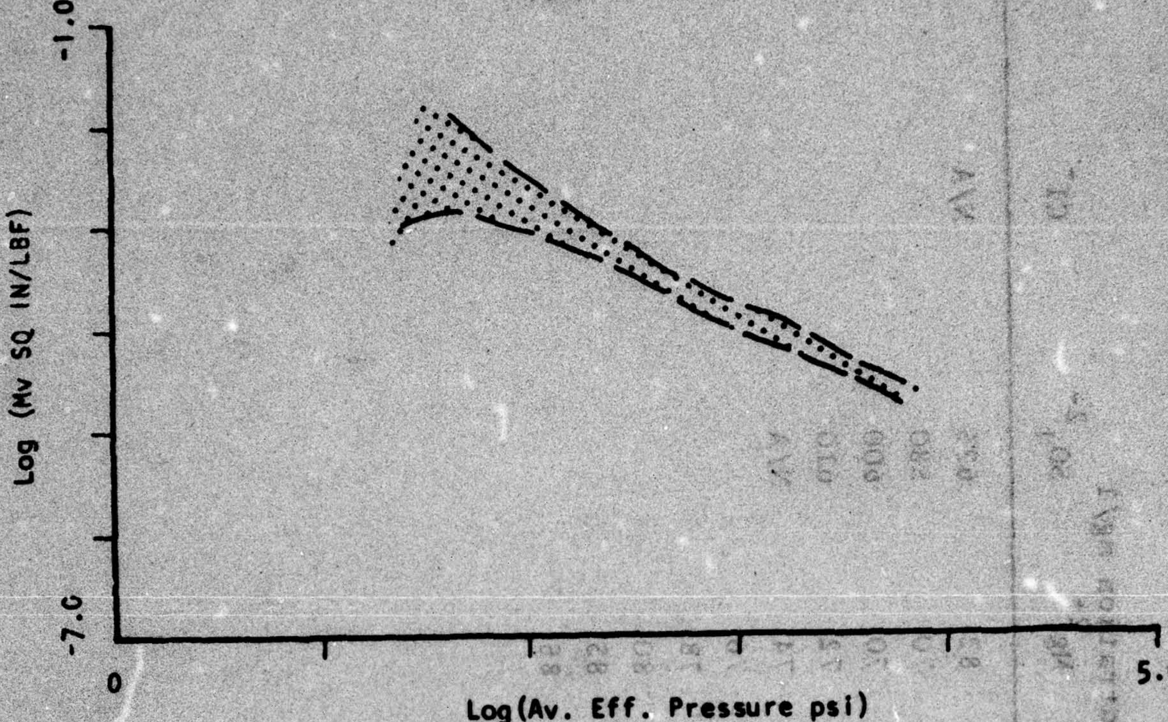
BC CMP 19



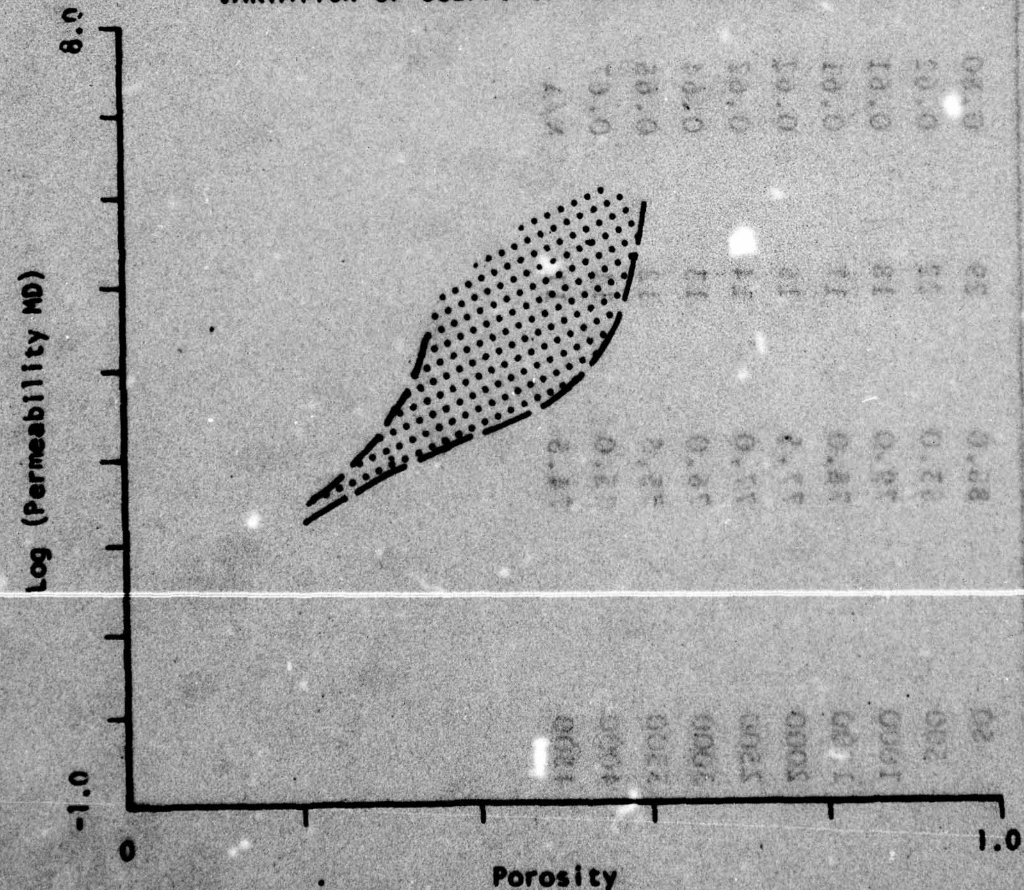
CHANGE IN THICKNESS OF SAMPLE WITH TIME



VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE



VARIATION OF COEFF. OF VOLUME DECREASE WITH EFFECTIVE PRESSURE



VARIATION OF PERMEABILITY WITH POROSITY

TABLE 7.18

Results of chemical analysis of pore fluids expelled from BC CHP 19

Axial Pressure (lbf/in^2)	Concentration mg/1						
	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
50	88.0	29	0.80	82	625	N/A	2500
500	83.0	22	0.62	70	580		1800
1000	79.0	18	0.61	70	600		2300
1500	78.0	17	0.61	72	610		2700
2000	77.5	15	0.62	74	N/A		3000
2500	77.0	14	0.62	76			3200
3000	76.0	13	0.64	78			3400
3500	75.5	12	0.65	80			3500
4000	75.0	11	0.67	83			3550
4500	74.5	11	N/A	85			3600

TEST NO. BC CHP 20 **Date: 15.12.73**

DETAILS OF TEST MATERIAL

Clay type; Ball clay; properties as in Table 7.12
State of original sample; remoulded in hypersaline water

TYPE OF TEST

Rate of loading; 2 psi per minute
Salinity of the pore fluid initially; 2 x normal salinity
Maximum consolidating pressure; 6800 psi

PROPOSED INVESTIGATION

To complete the series of tests investigating the influence of rate of loading and salinity on compaction behaviour

INITIAL CONDITION OF THE SAMPLE

Moisture Content; 80.0 per cent
Thickness; 5.80 inches
Weight; 3.809 lbf

PRECONSOLIDATION STAGE

Rate of strain; 0.0017 inches/minute
Maximum preconsolidation stress; 85 psi
Moisture content after preconsolidation; (information lost)
Thickness after preconsolidation; 3.822 inches
Weight after preconsolidation; 2.921 lbf

LOADING STAGE

Total decrease in thickness; 1.095 inches

UNLOADING STAGE

Rate of unloading; 2 psi per minute
Total rebound of the sample; 0.168 inches

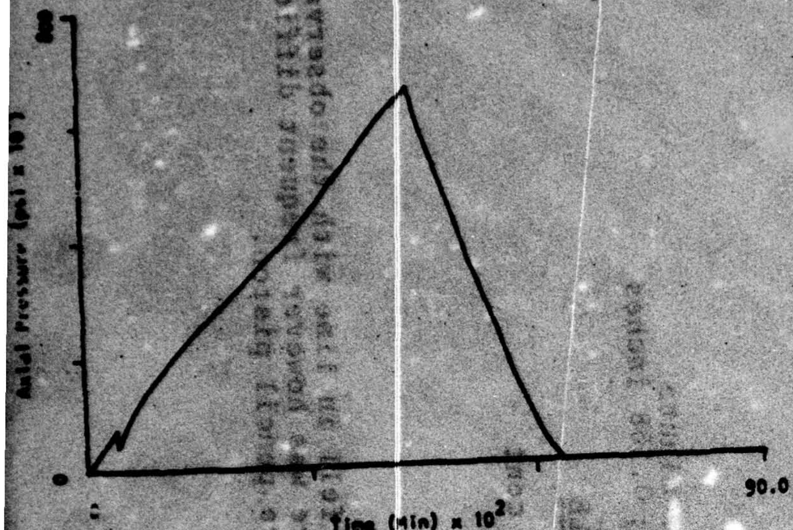
FINAL CONDITION OF THE SAMPLE

Moisture content; 20.45 per cent
Thickness; 2.850 inches

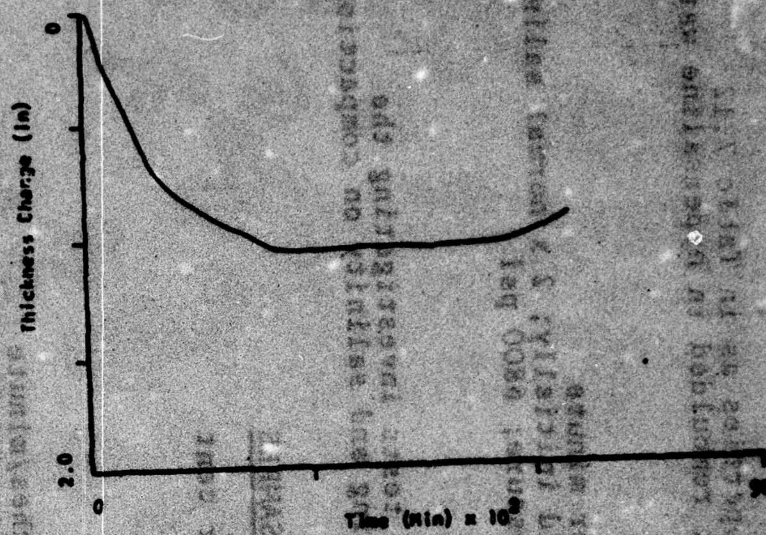
FURTHER COMMENTS

This test gave results that fell in line with the observations of the previous tests. There was however frequent difficulty with the sticking of pressure pencil piston.

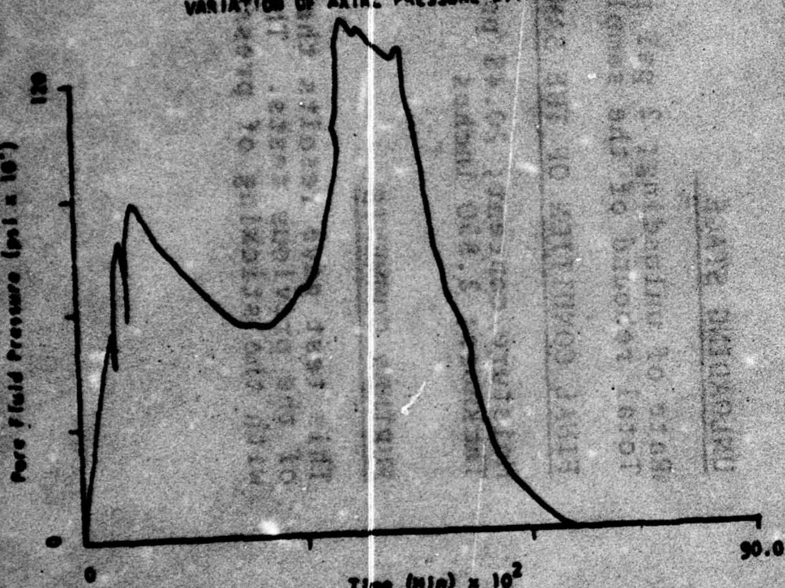
DC CMP 20



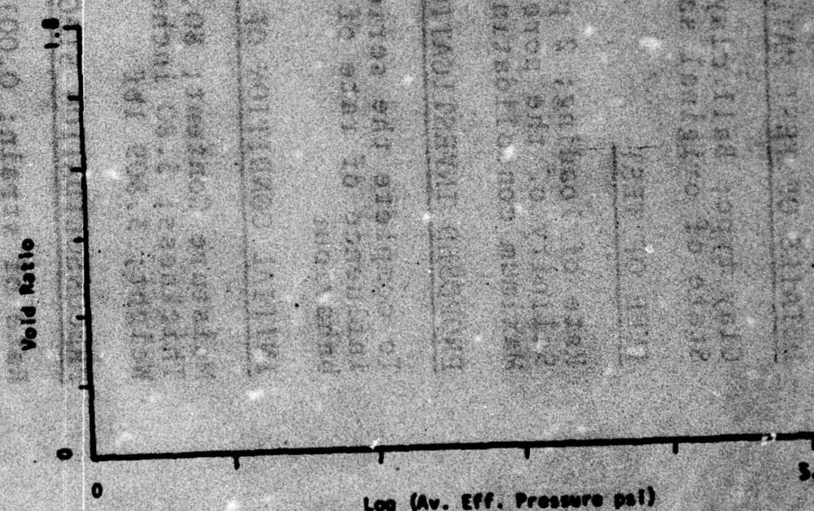
VARIATION OF AXIAL PRESSURE WITH TIME



CHANGE IN THICKNESS OF SAMPLE WITH TIME



VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME



VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE

TABLE 7.19

Results of chemical analysis of pore fluids expelled from BC CHP 20

Axial Pressure (lbf/in^2)	Concentration g/1 Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
50	10.75	0.38	1.50	0.95	1.77	31.0	38.0
500	9.95	0.35	1.41	0.95	1.75	30.1	36.2
1000	9.70	0.32	1.42	0.96	1.72	30.5	36.3
1500	9.60	0.31	1.45	1.00	1.71	30.6	36.8
2000	9.50	0.30	1.46	1.00	1.72	30.7	37.0
2500	9.49	0.29	1.46	1.00	1.73	30.7	37.4
3000	9.49	0.29	1.46	0.96	1.74	30.8	37.8
3500	9.49	0.29	1.46	0.96	1.75	30.8	38.0
4000	9.45	0.29	1.46	0.96	1.76	30.6	38.6

TEST NO. BC CHP 21 Date; 20.12.73

DETAILS OF TEST MATERIAL

Clay Type; Ball Clay; properties in Table 7.12
State of original sample; remoulded in hypersaline water

TYPE OF TEST

Rate of loading; ½ lbf/sq.in./minute
Salinity of the pore fluid initially; 2 x normal salinity
Maximum consolidating pressure; 6825 lbf/sq in

PROPOSED INVESTIGATION

A further hypersaline test to investigate its influence on the observed parameters

INITIAL CONDITION OF THE SAMPLE

Moisture content; 120.0
Thickness; 5.880
Weight; 1713 gms

PRECONSOLIDATION STAGE

Rate of strain; 0.00001 ins/minute
Maximum consolidation stress; 50 lbf/sq in
Moisture content after preconsolidation; 67.92 per cent
Thickness after preconsolidation; 3.138 inches
Weight after preconsolidation; 1268.00 gms

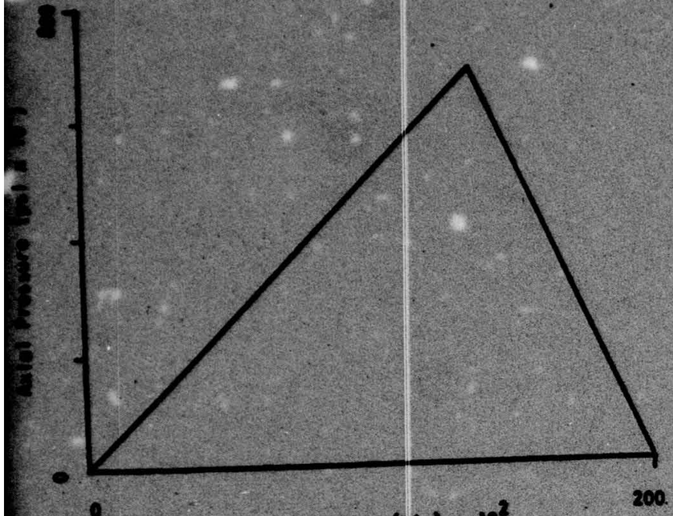
LOADING STAGE

Total decrease in thickness; 1.061 ins

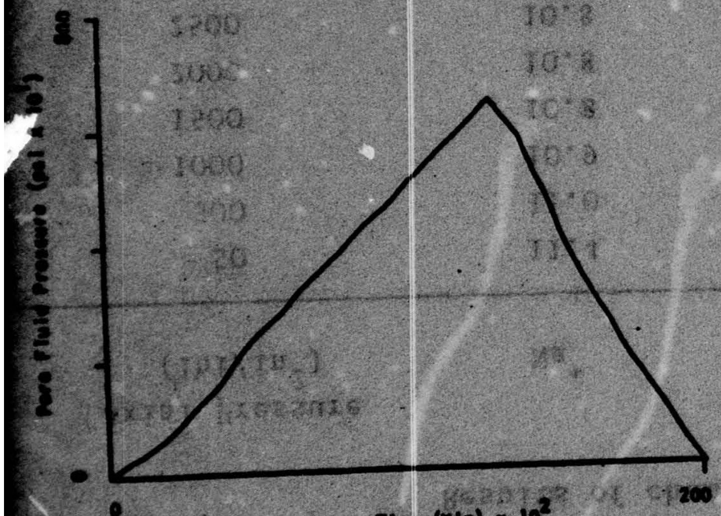
FINAL CONDITION OF SAMPLE

Moisture content; 20.45 per cent
Thickness; 2.850 ins
Weight; 847.09 gms

BC CMP 21

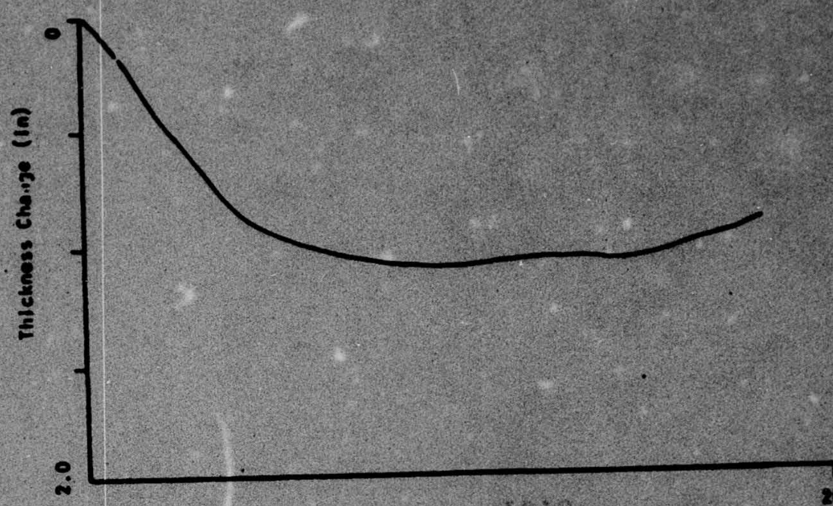


VARIATION OF AXIAL PRESSURE WITH TIME

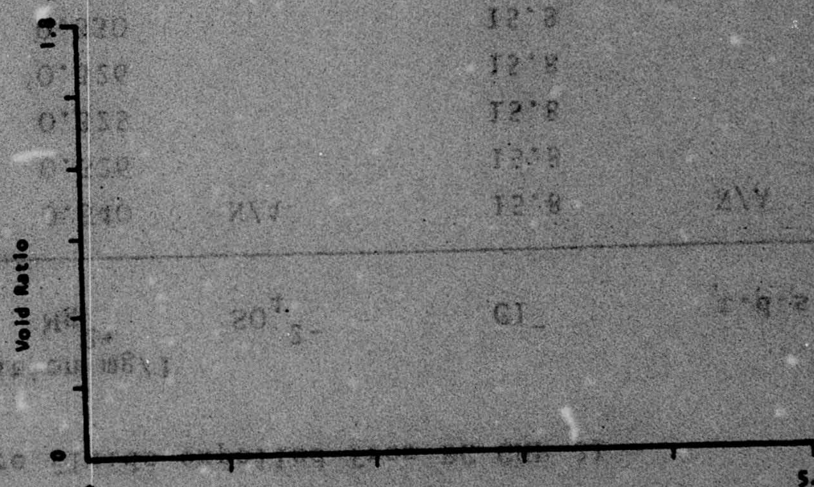


VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME

BC CMP 21



CHANGE IN THICKNESS OF SAMPLE WITH TIME



VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE

TABLE 7.20

Results of chemical analysis of pore fluids expelled from BC CHP 21

Axial Pressure (lbf/in^2)	Concentration mg/l						
	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
50	11.4	0.55	0.275	0.340	N/A	15.8	N/A
500	11.0	0.52	0.270	0.326		15.8	
1000	10.9	0.50	0.270	0.325		15.8	
1500	10.8	0.49	0.270	0.326		15.8	
2000	10.8	0.48	0.270	0.330		15.8	
2500	10.8	0.48	0.270	0.335		15.8	
3000	11.0	0.48	0.274	0.345		15.9	
3500	11.1	0.48	0.274	0.350		16.0	

TEST NO. BC CHP 22 **Date: 7.3.75**

DETAILS OF TEST MATERIAL

Ball clay (BC 983) sedimented in distilled water.

TYPE OF TEST

Rate of loading; 10 psi/hr
Rate of unloading; 20 psi/hr
Salinity of initial pore fluid; non saline
Maximum consolidation pressure;

PROPOSED INVESTIGATION

Consolidation of Ball clay.

FURTHER COMMENTS

Test abandoned as slurry was too wet to assemble in the Cell without risk of clogging up pressure head assembly.

TEST NO. N BC CHP 1 **Date: 25.6.74**

DETAILS OF TEST MATERIAL

Clay type; Ball clay (Stoneware); properties in Table 7.12

State of original sample; undisturbed trimmed from blocks

TYPE OF TEST

Rate of loading; 1 lbf/sq in/minute

Maximum consolidating pressure; 7800 lbf/sq in

PROPOSED INVESTIGATION

To determine consolidation character of overconsolidated clay

To estimate the preconsolidation load

INITIAL CONDITION OF SAMPLE

Moisture content; 23.5 per cent

Thickness; 3.09 inches

Weight; 1248.00 gms

LOADING SPACE

Total compaction; 1.38 inches

UNLOADING STAGE

Rate of unloading; 2 lbf/sq in/minute

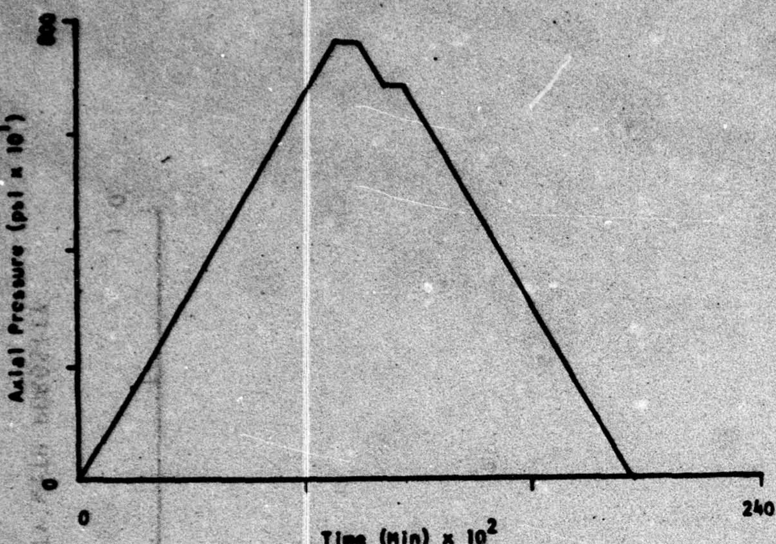
FINAL CONDITION OF SAMPLE

Moisture content; 18.30 per cent

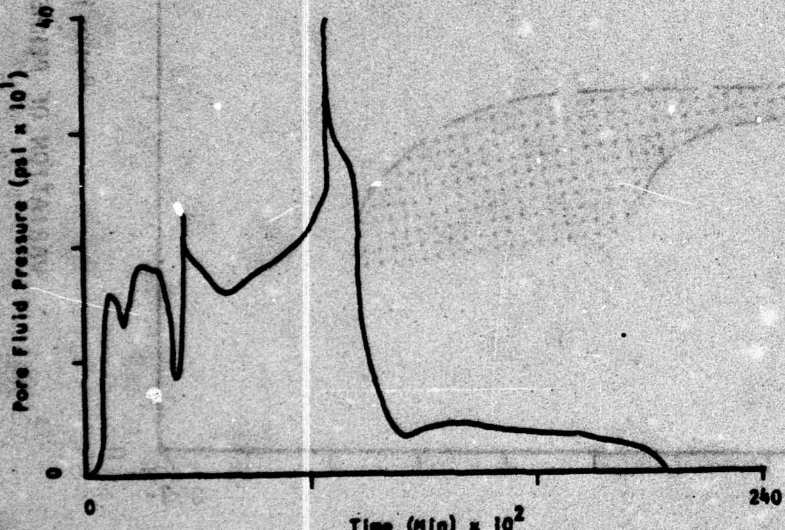
Thickness; 2.710 inches

Weight; 1164.00 gms

N BC CHP 1

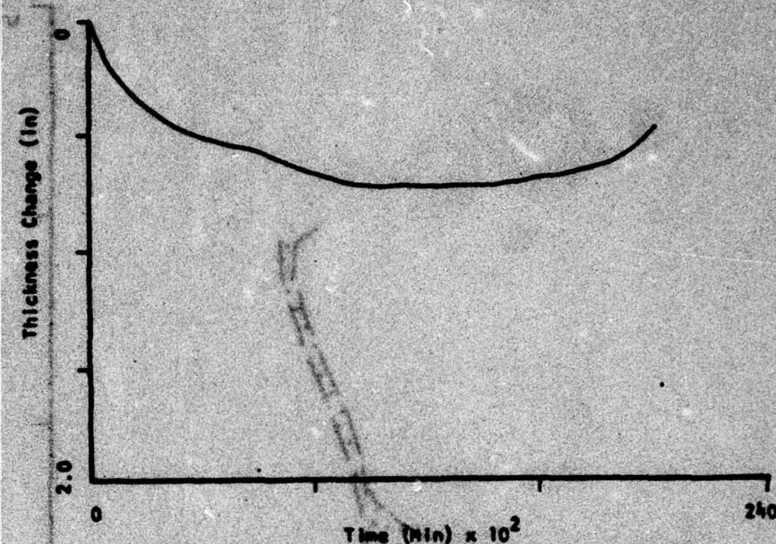


VARIATION OF AXIAL PRESSURE WITH TIME

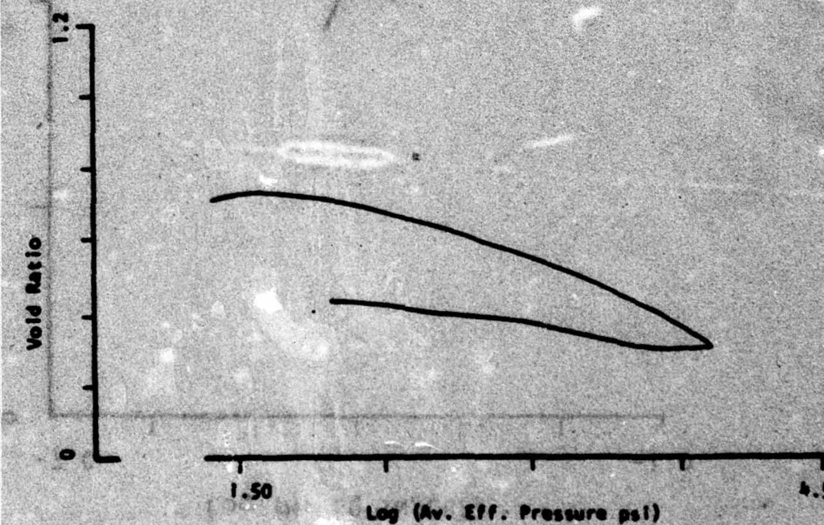


VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME

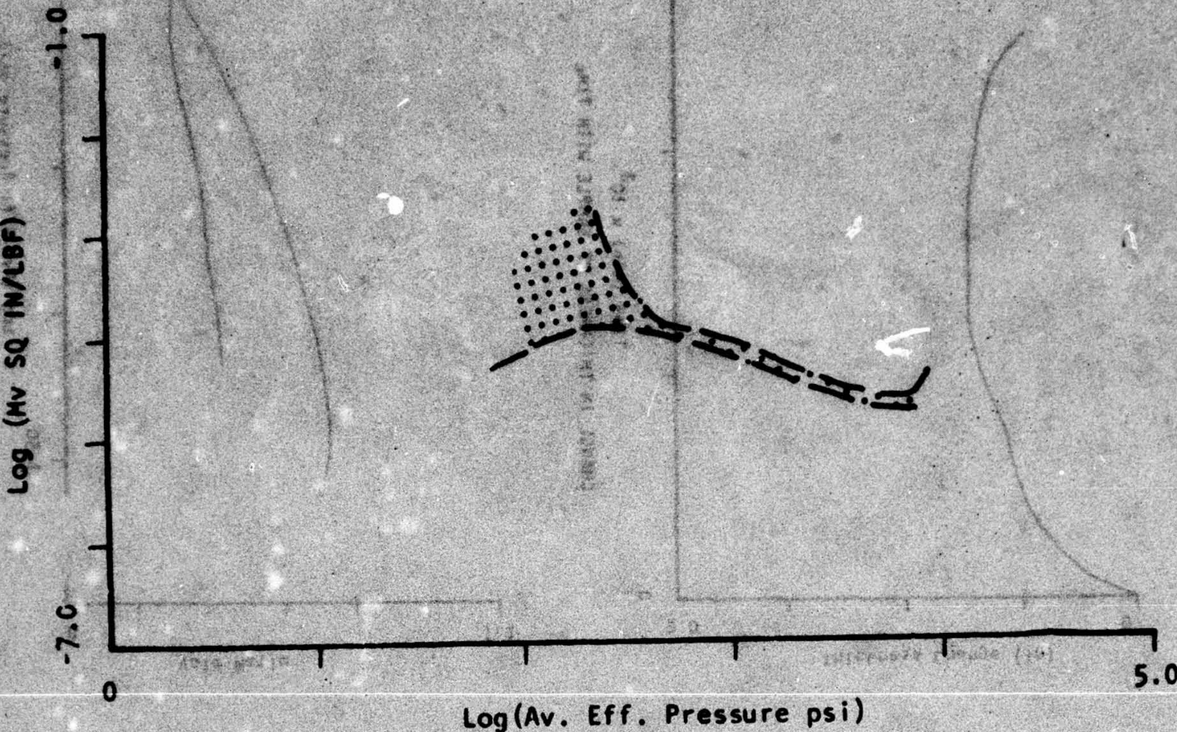
N BC CHP 1



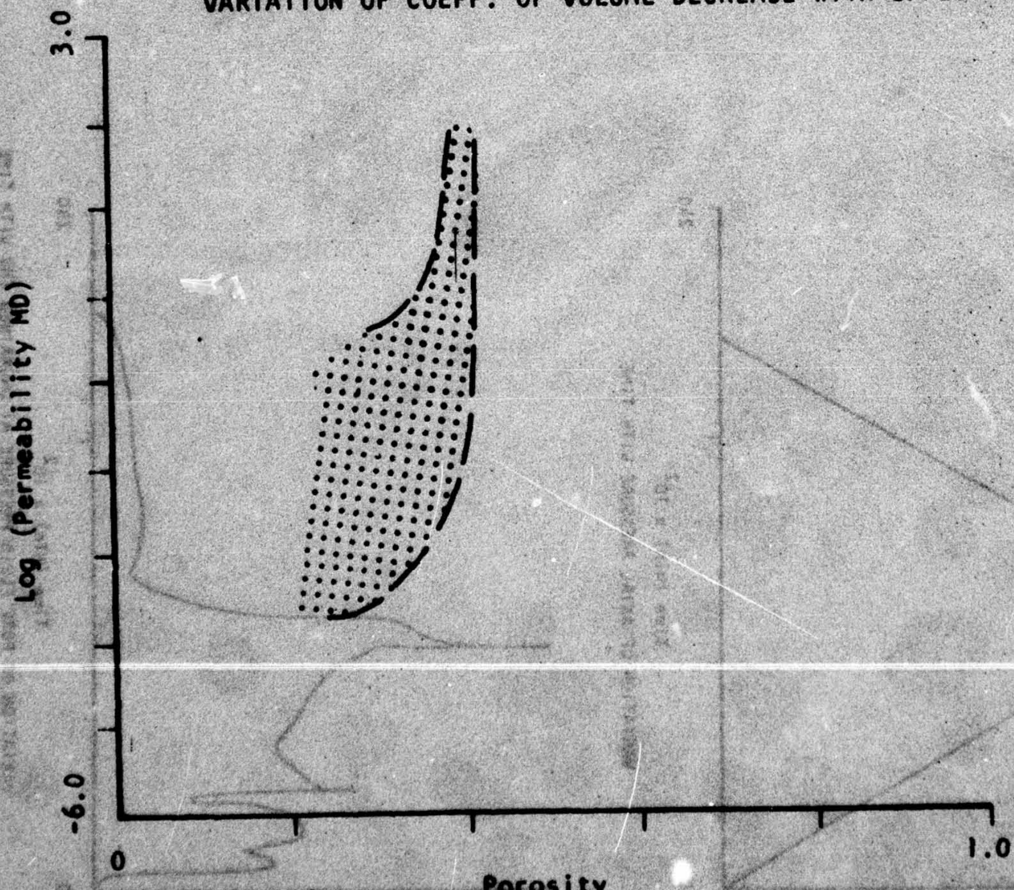
CHANGE IN THICKNESS OF SAMPLE WITH TIME



VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE



VARIATION OF COEFF. OF VOLUME DECREASE WITH EFFECTIVE PRESSURE



VARIATION OF PERMEABILITY WITH POROSITY

TABLE 7.21

Results of chemical analysis of pore fluids expelled from N BC CHP 1

Axial Pressure MN/m^2	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
	Concentration mg/l						
50	50	8.5	50	9.0	trace only	trace only	500
500	44	7.6	44	7.5			520
1000	38	6.4	40	6.5			560
1500	34	5.5	35	6.0			600
2000	30	4.7	31	5.0			660
2500	27	4.4	27	4.5			700
3000	26	4.2	25	4.0			760
3500	24	4.0	26	3.5			800
4000	22	3.9	28	3.0			860

TEST NO. N FA CHP 2 Date 10.9.74

DETAILS OF TEST MATERIAL

Clay type; Kaolinitic sediments (Falmouth)

State of sample; undisturbed collected in required size from the field

TYPE OF TEST

Rate of loading; 1 lbf/sq in/minute

Maximum consolidation pressure; 4300 lbf/sq in

PROPOSED INVESTIGATION

To determine consolidation of character (high pressure) of normally consolidated clay

INITIAL CONDITION OF SAMPLE

Moisture content; 52.95 per cent

Thickness; 3.685 inches

Weight; 1300.0 gms

LOADING STAGE

Total compaction; 1.365 inches

UNLOADING STAGE

Rate of unloading; 2 lbf/sq in/minute

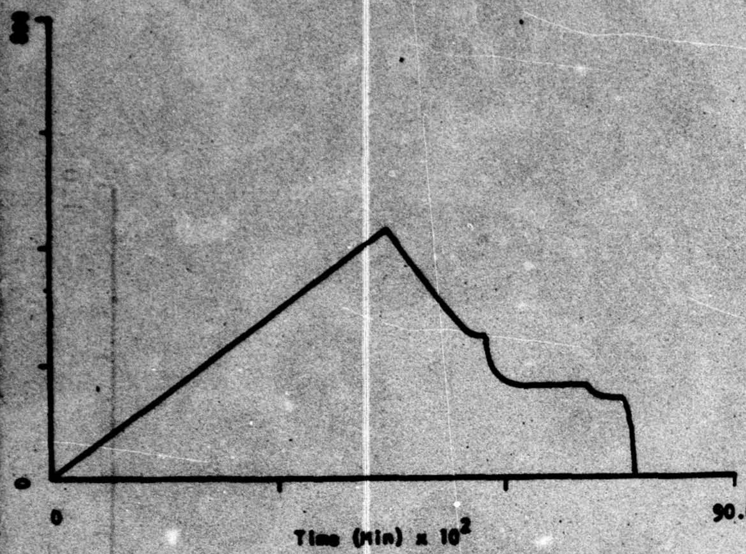
FINAL CONDITION OF SAMPLE

Moisture content; 17.92

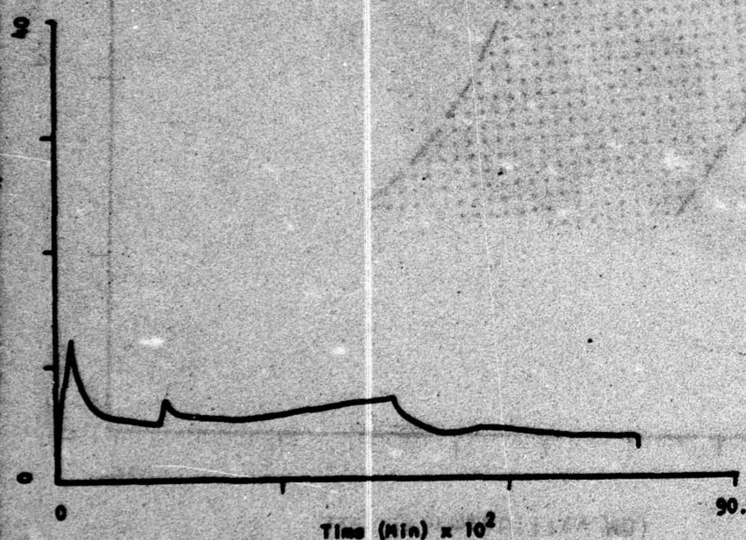
Thickness; 2.321 inches

Weight; 985.00 gms

N FA CHP 2

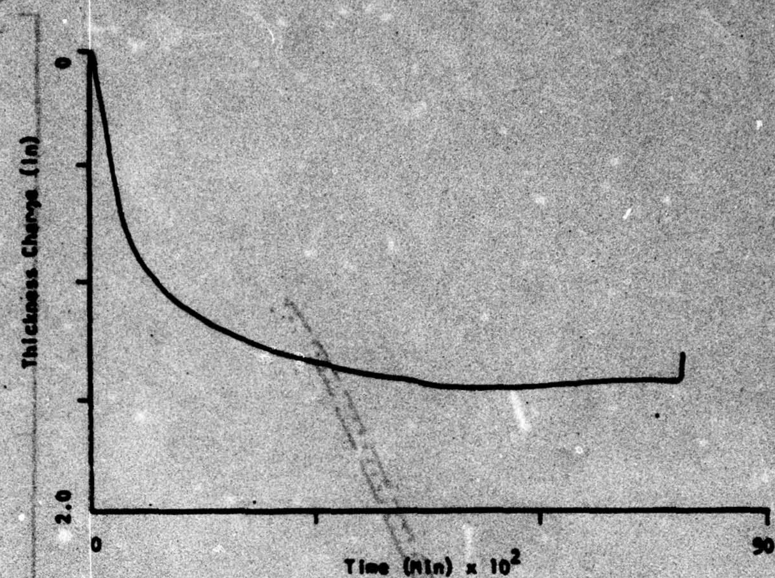


VARIATION OF AXIAL PRESSURE WITH TIME

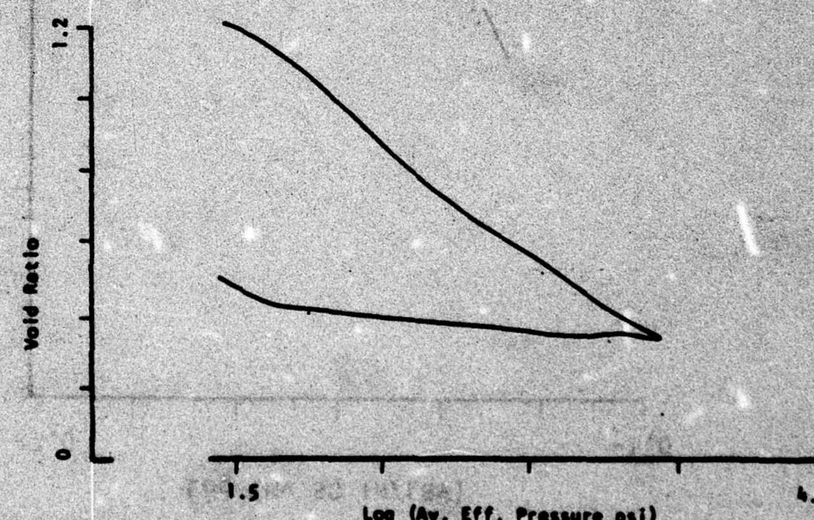


VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME

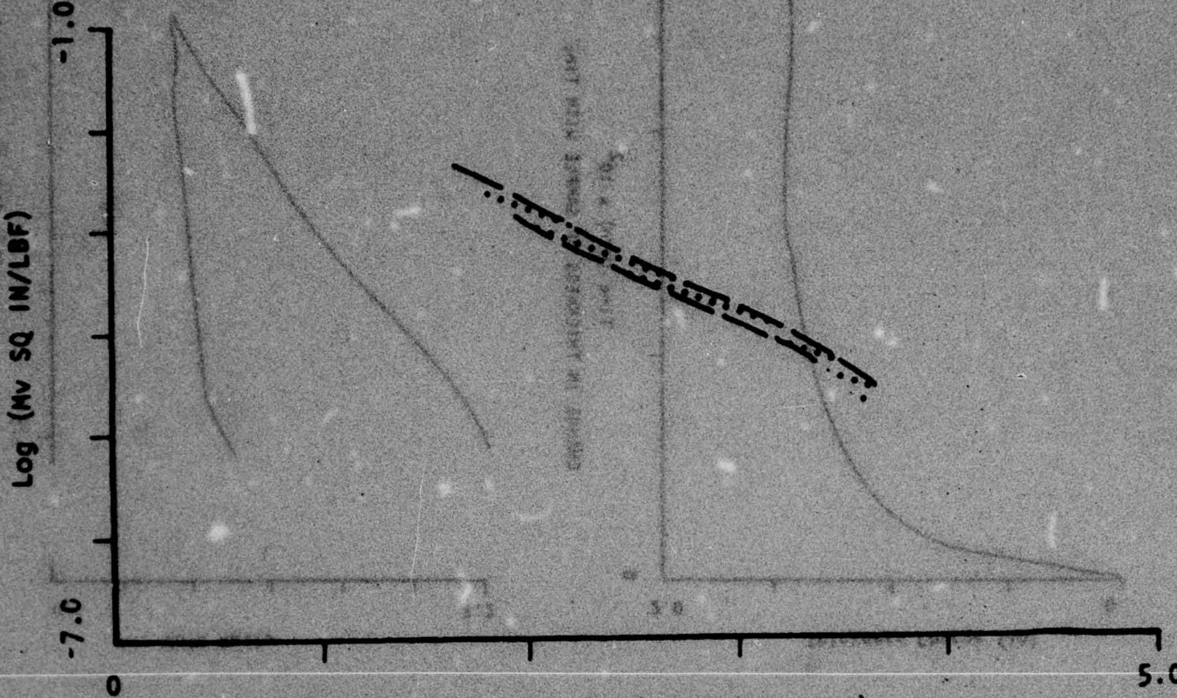
N FA CHP 2



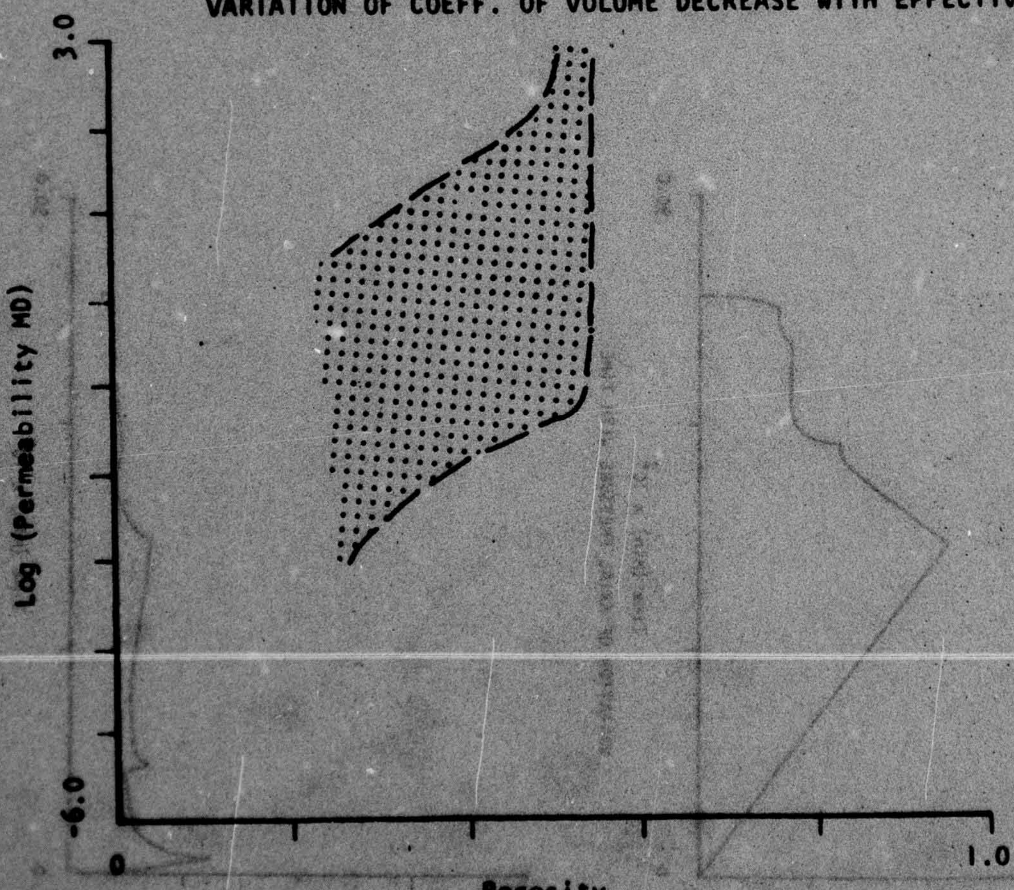
CHANGE IN THICKNESS OF SAMPLE WITH TIME



VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE



VARIATION OF COEFF. OF VOLUME DECREASE WITH EFFECTIVE PRESSURE



VARIATION OF PERMEABILITY WITH POROSITY

TABLE 7.22

Results of chemical analysis of pore fluids expelled from N FA CHP 2

Axial Pressure (lbf/in^2)	Concentration g/l						
	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s
50	8.5	0.450	0.180	0.375	2.80	12.80	N/A
500	8.3	0.430	0.170	0.360	2.50	12.60	
1000	8.2	0.425	0.160	0.355	2.48	12.60	
1500	8.1	0.415	0.155	0.350	2.30	12.65	
2000	8.0	0.410	0.150	0.350	2.28	12.70	
2500	8.0	0.400	0.150	0.349	2.26	12.70	
3000	8.0	0.400	0.150	0.349	2.25	12.75	
3500	7.9	0.400	0.150	0.349	2.21	12.8	
4000	7.[illegible]	0.400	0.150	0.349	2.20	12.8	

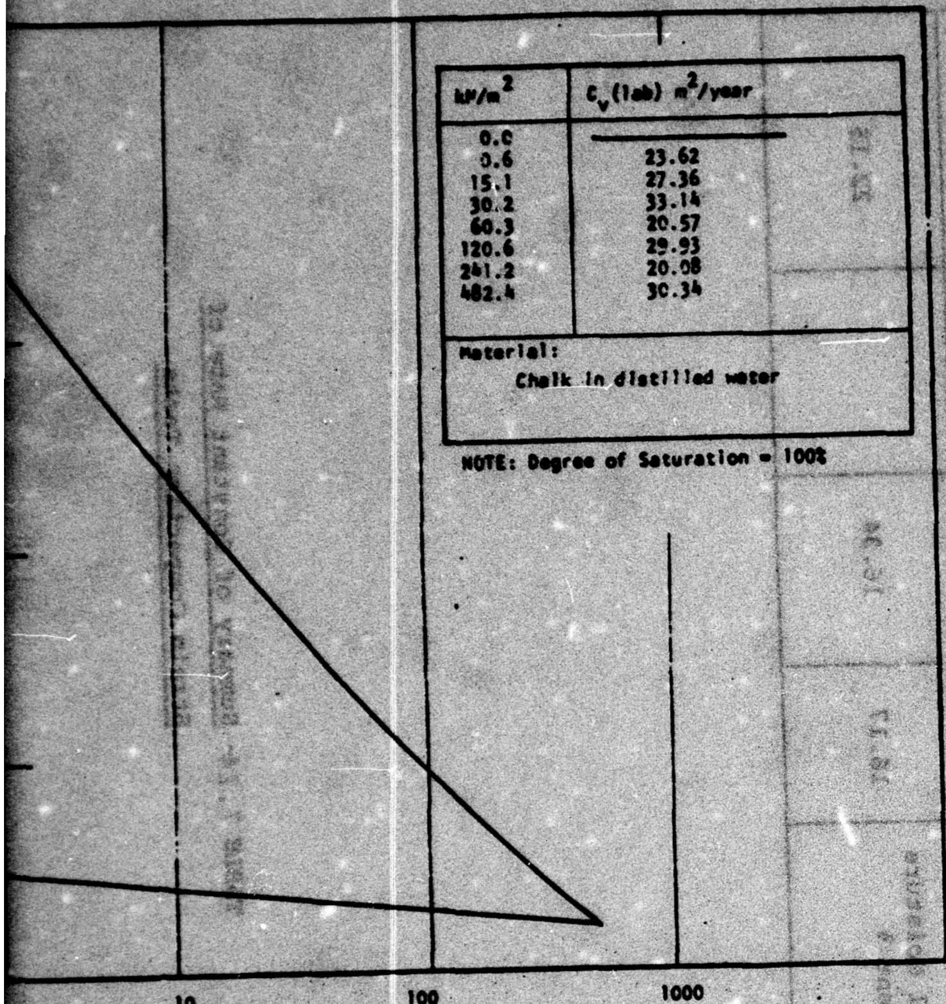
Table 7.23 - Summary of Low Pressure-Temperature Compaction Tests

	BC. CLP.							
Test No.	RT1	T1	RT2	T2	RT3	T3	RT4	T4
Date of Test	22.7.73	22.7.73	4.9.73	4.9.73	29.9.73	29.9.73	14.10.73	14.10.73
Total No. of Days	14	14	14	14	14	14	9	9
Maximum Compaction Press psi	140	140	140	140	140	140	140	140
Temperature of Heater °C	17	50	17	58	17	49	17	70
Temperature Gradient in Sample oc/inch	0	6	0	5	0	5	0	5
Unloading	Stages	Stages	Instant	Instant	Stages	Stages	Stages	Stages
Final Moisture Content	42.50	42.10	41.70	41.50	42.45	40.60	40.00	37.70
Initial Thickness	1.6875	1.687	1.875	1.875	1.875	1.875	1.875	1.875

	BC. CRS			
Test No.	1	2	3	4
Date	4-1-74	21-1-74	13-2-74	1-3-74
Total No. of Days	8	8	4	8
Maximum Pressure psi	2830	814	failure	3450
Rate of Strain inches/min	0.0007	0.0049	.0049	0.0049
Final Moisture Content %	16.17	16.34		22.15

TABLE 7.24- Summary of Constant Rate of Strain Compaction Tests

C1

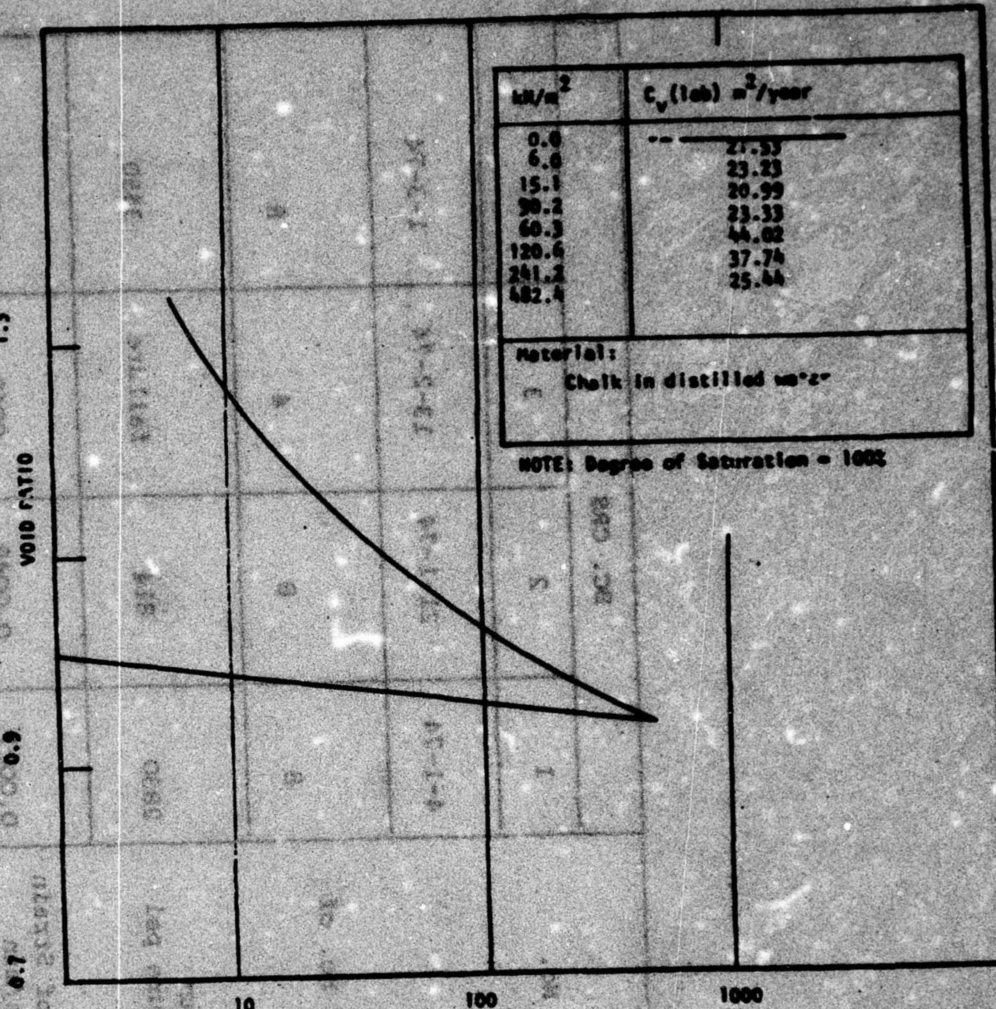


kN/m²	C_v(lab) m²/year
0.0	
0.6	23.62
15.1	27.36
30.2	33.14
60.3	20.57
120.6	29.93
241.2	20.08
482.4	30.34
Material: Chalk in distilled water	

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 23.8 : 13.6		(dia x ht : final thickness)
Moisture content (%)	48.0	25.7	(initial then final)
Temperature (^oC)	17.0		
Shrinkage Limit (%)	1.4		
Initial void ratio:	1.548		
Oc:	0.242		

C 2

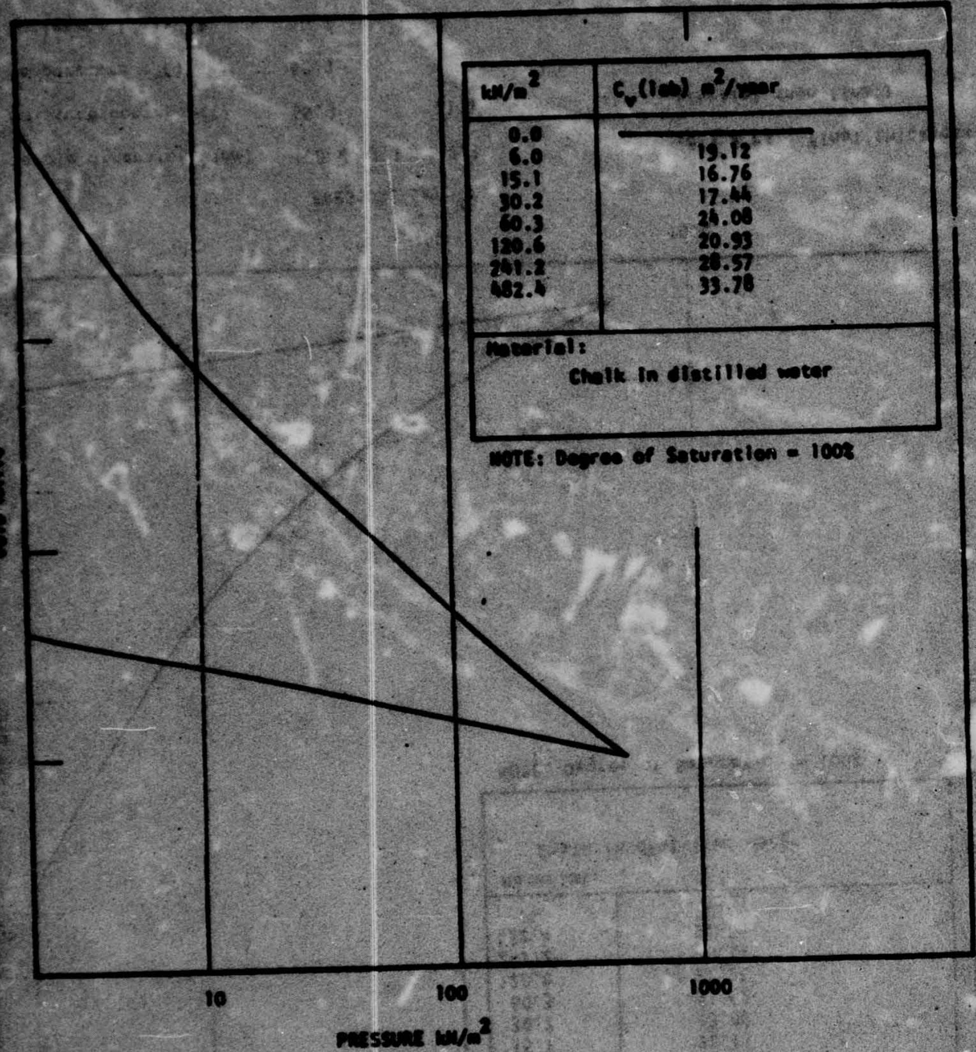


kN/m²	C_v(lab) m²/year
0.0	--
6.6	27.33
15.1	23.23
30.2	20.99
60.3	23.33
120.6	44.02
241.2	37.74
482.4	25.44
Material: Chalk in distilled water	

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 20.1 : 14.5		(dia x ht : final thickness)
Moisture content (%)	65.8	29.4	(initial then final)
Temperature (^oC)	30.0		
Shrinkage Limit (%)	0.7		
Initial void ratio:	1.791		
Oc:	0.150		

C3



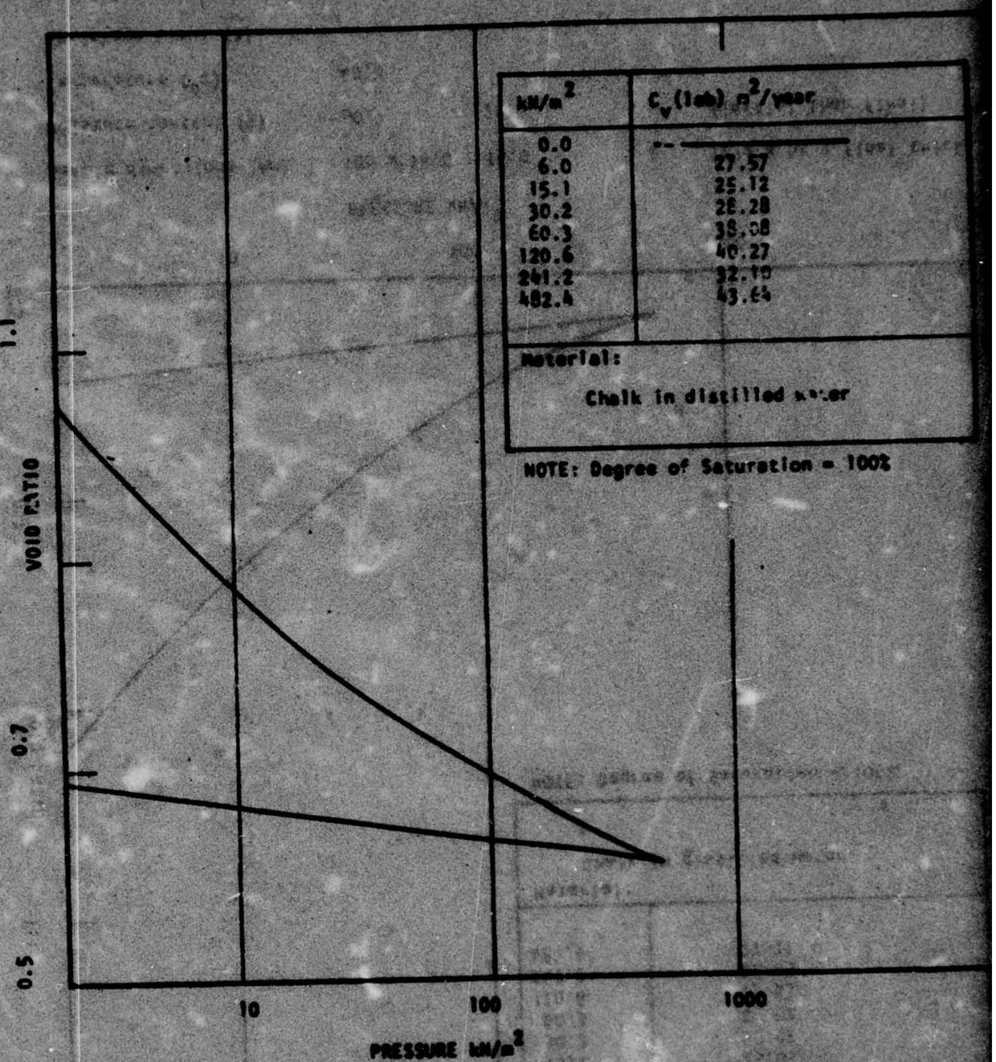
kN/m²	C_v(lab) m²/year
0.0	—
6.0	19.12
15.1	16.76
30.2	17.44
60.3	24.08
120.6	20.93
241.2	28.57
482.4	33.78

Material:
Chalk in distilled water

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 16.8 : 12.5		(dia x ht : final thickness)
Moisture content (%)	55.6	21.6	(initial then final)
Temperature (°C)	40.0		
Shrinkage Limit (%)	0.7		
Initial void ratio:	1.089		
Oc:	0.145		

C4



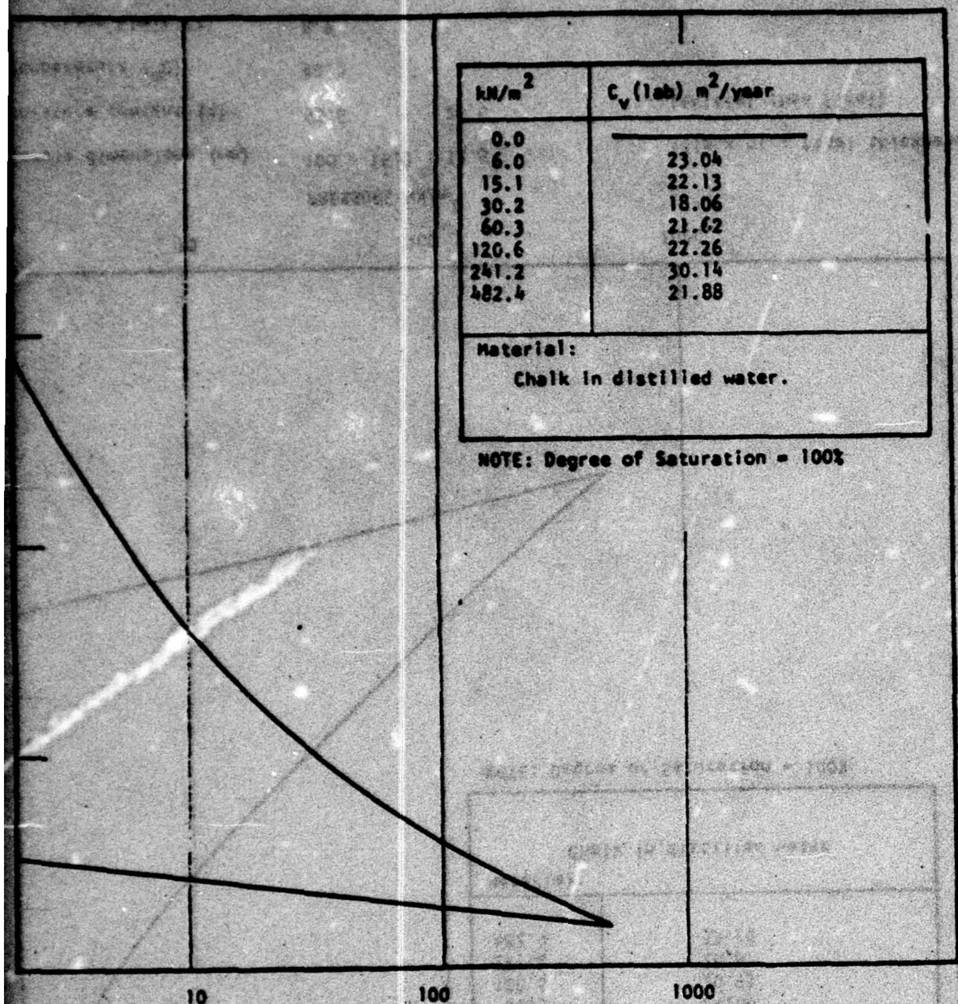
kN/m²	C_v(lab) m²/year
0.0	--
6.0	27.57
15.1	25.12
30.2	28.28
60.3	38.08
120.6	40.27
241.2	32.10
482.4	43.64

Material:
Chalk in distilled water

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 17.5 : 14.0		(dia x ht : final thick
Moisture content (%)	58.6	24.2	(initial then final)
Temperature (°C)	50.0		
Shrinkage Limit (%)	0.7		
Initial void ratio:	1.122		
Oc:	0.122		

C5



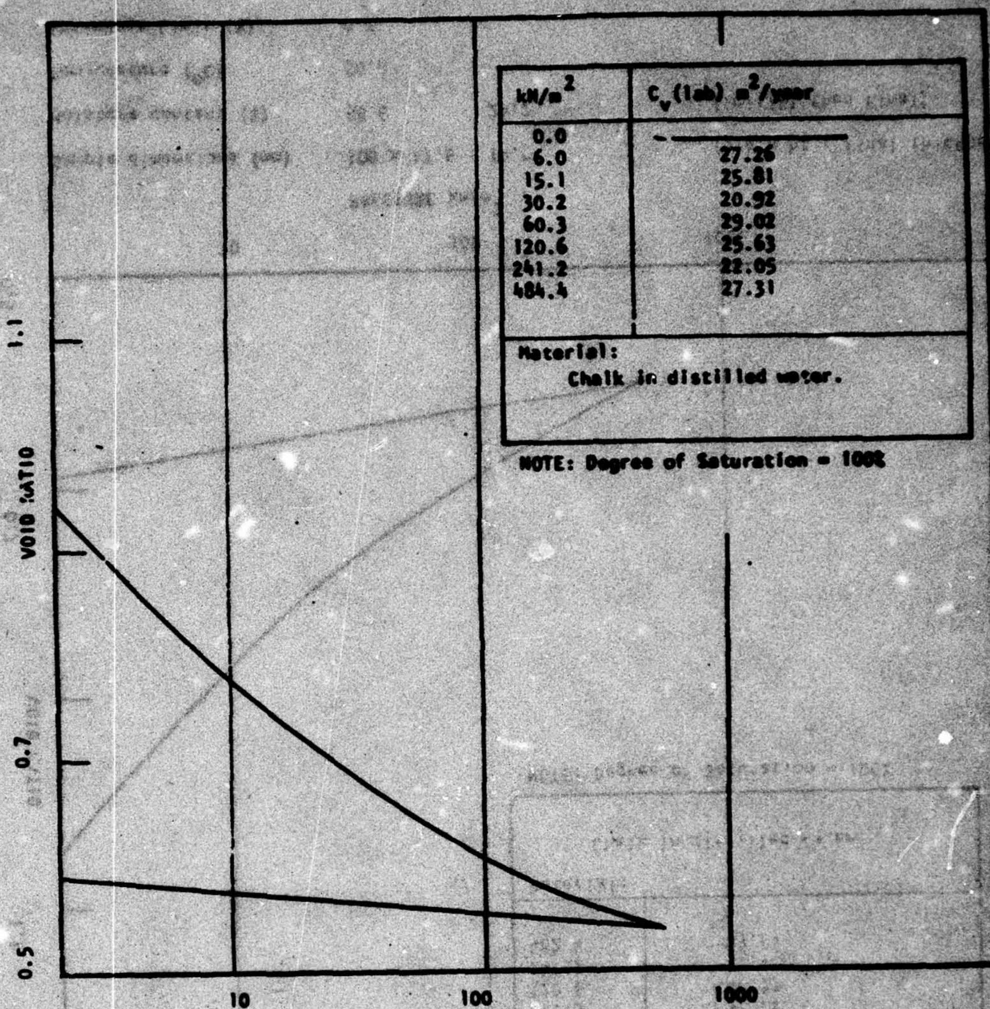
kN/m²	C_v(lab) m²/year
0.0	—
6.0	23.04
15.1	22.13
30.2	18.06
60.3	21.62
120.6	22.26
241.2	30.14
482.4	21.88

Material:
Chalk in distilled water.

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 17.1 : 12.3		(dia x ht : final thickness)
Moisture content (%)	56.0	21.1	(initial then final)
Temperature (°C)	60.0		
Shrinkage Limit (%)	0.7		
Initial void ratio:	1.111		
Oc:	0.124		

C6



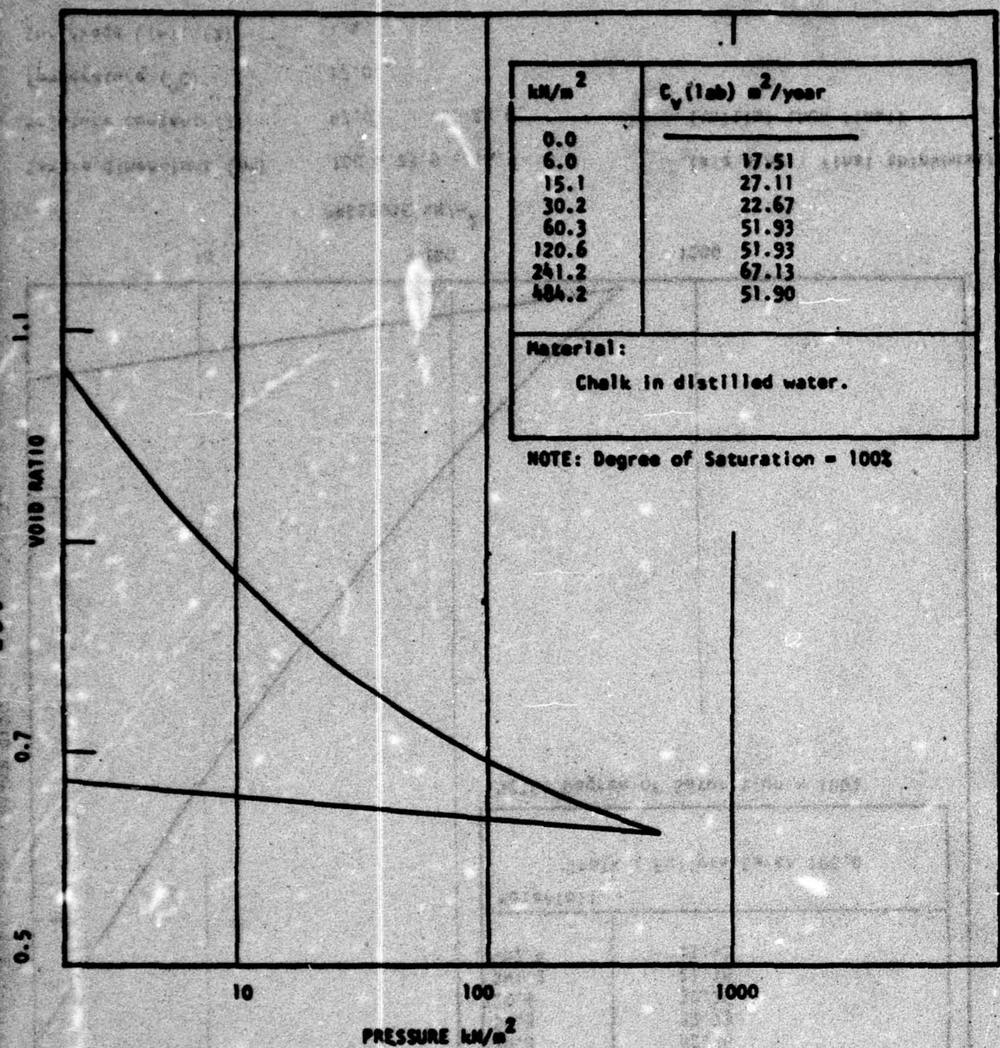
kN/m²	C_v(lab) m²/year
0.0	—
6.0	27.26
15.1	25.81
30.2	20.92
60.3	29.02
120.6	25.63
241.2	22.05
484.4	27.31

Material:
Chalk in distilled water.

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 18.0 : 14.0		(dia x ht : final thickness)
Moisture content (%)	50.7	22.0	(initial then final)
Temperature (°C)	40.0		
Shrinkage Limit (%)	-		
Initial void ratio:	1.048		
Oc:	0.109		

C7



kN/m²	C_v(lab) m²/year
0.0	
6.0	17.51
15.1	27.11
30.2	22.67
60.3	51.93
120.6	51.93
241.2	67.13
484.2	51.90

Material:

Chalk in distilled water.

Sample dimensions (mm)	100 x 19.4 : 15.0		(dia x ht : final thickness)
Moisture content (%)	52.5	23.9	(initial then final)
Temperature (°C)	20.0		
Shrinkage Limit (%)			
Initial void ratio:	1.167		
Oc:	0.155		

AD-A046 946 IMPERIAL COLL OF SCIENCE AND TECHNOLOGY LONDON (ENGLAND) F/G 8/13
ARTIFICIALLY SIMULATING THE GEOLOGICAL HISTORY OF CLAY.(U)
JUL 76 J L KNILL, B A CLARK, M H DEFREITAS DA-ERO-124-74-G-0085

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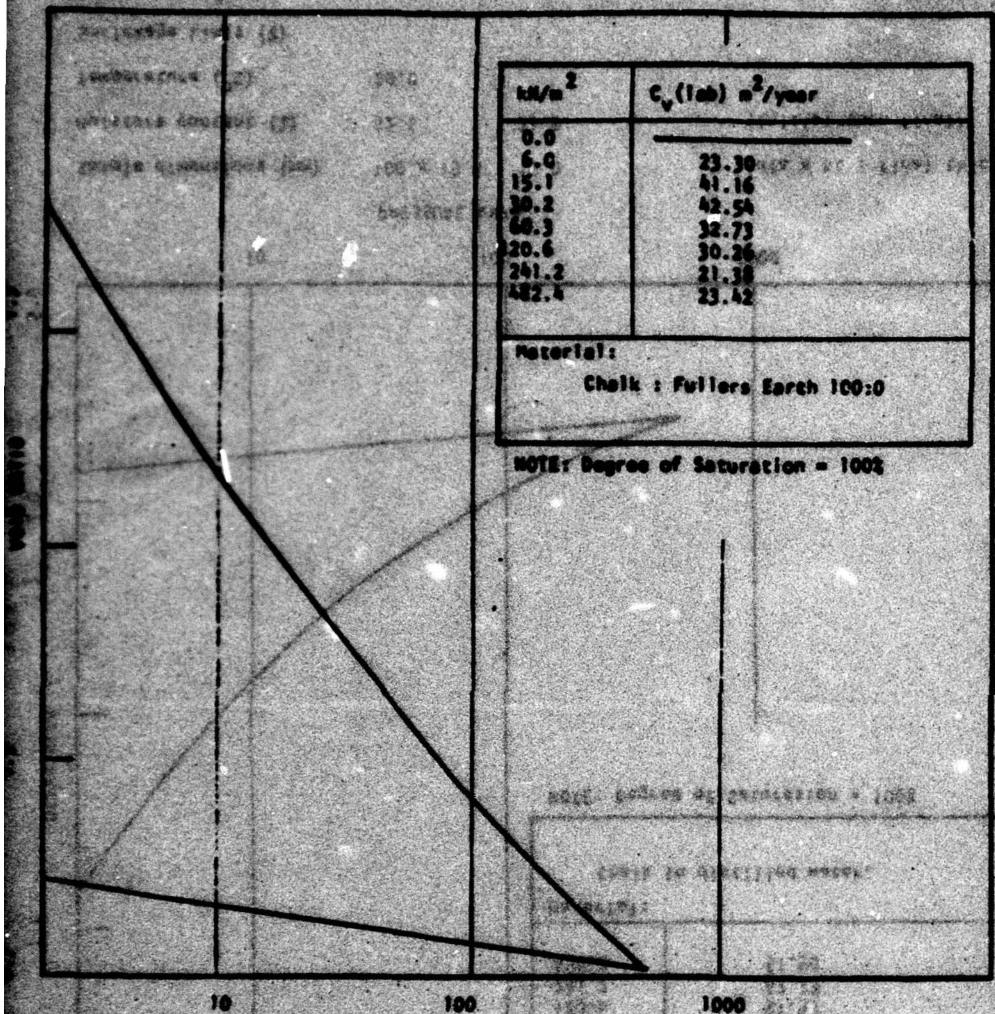
CF 1



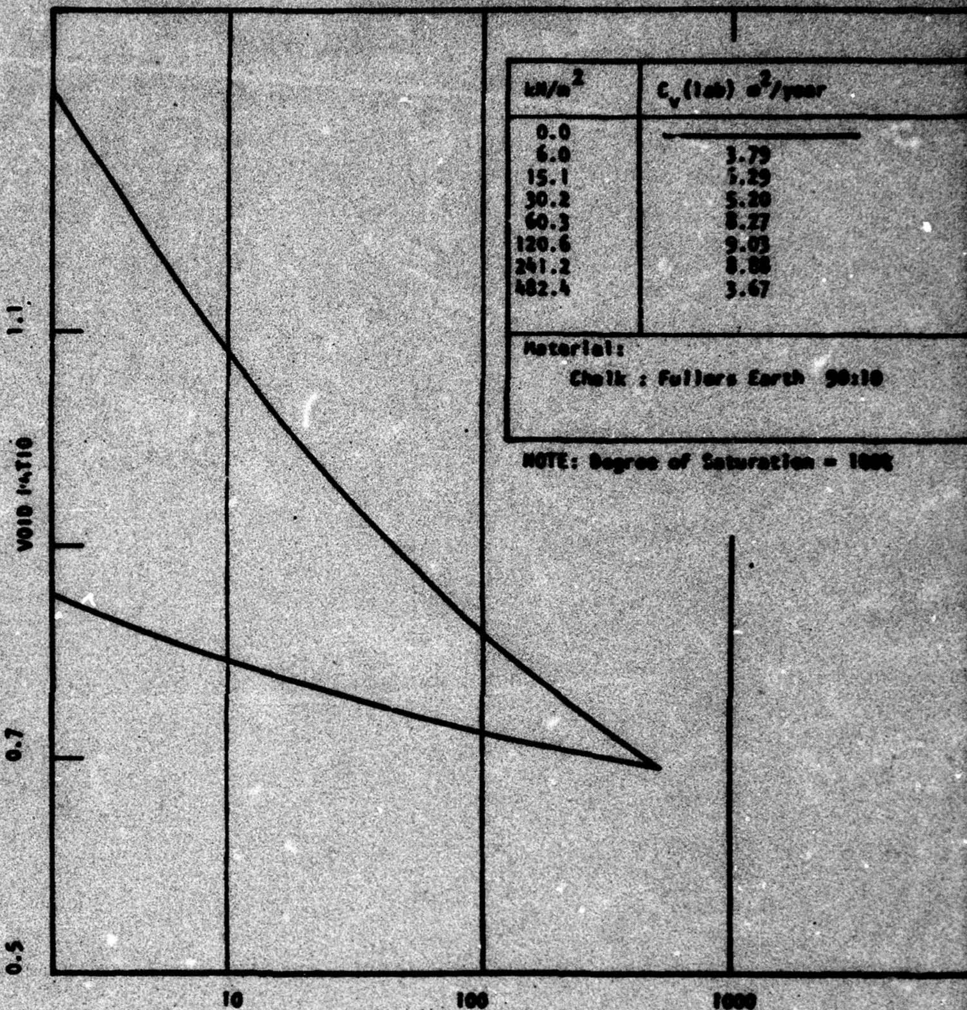
kN/m²	C_v(lab) m²/year
0.0	
6.0	23.30
15.1	41.16
30.2	42.54
60.3	32.73
120.6	30.26
241.2	21.38
482.4	23.42

Material:
Chalk : Fullers Earth 100:0

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 23.9 : 16.5		(dia x ht : final thickness)
Moisture content (%)	47.0	25.6	(initial then final)
Temperature (°C)	17.0		
Shrinkage Limit (%)	1.4		
Initial void ratio:	1.605		
Oc:	0.255		

CF2



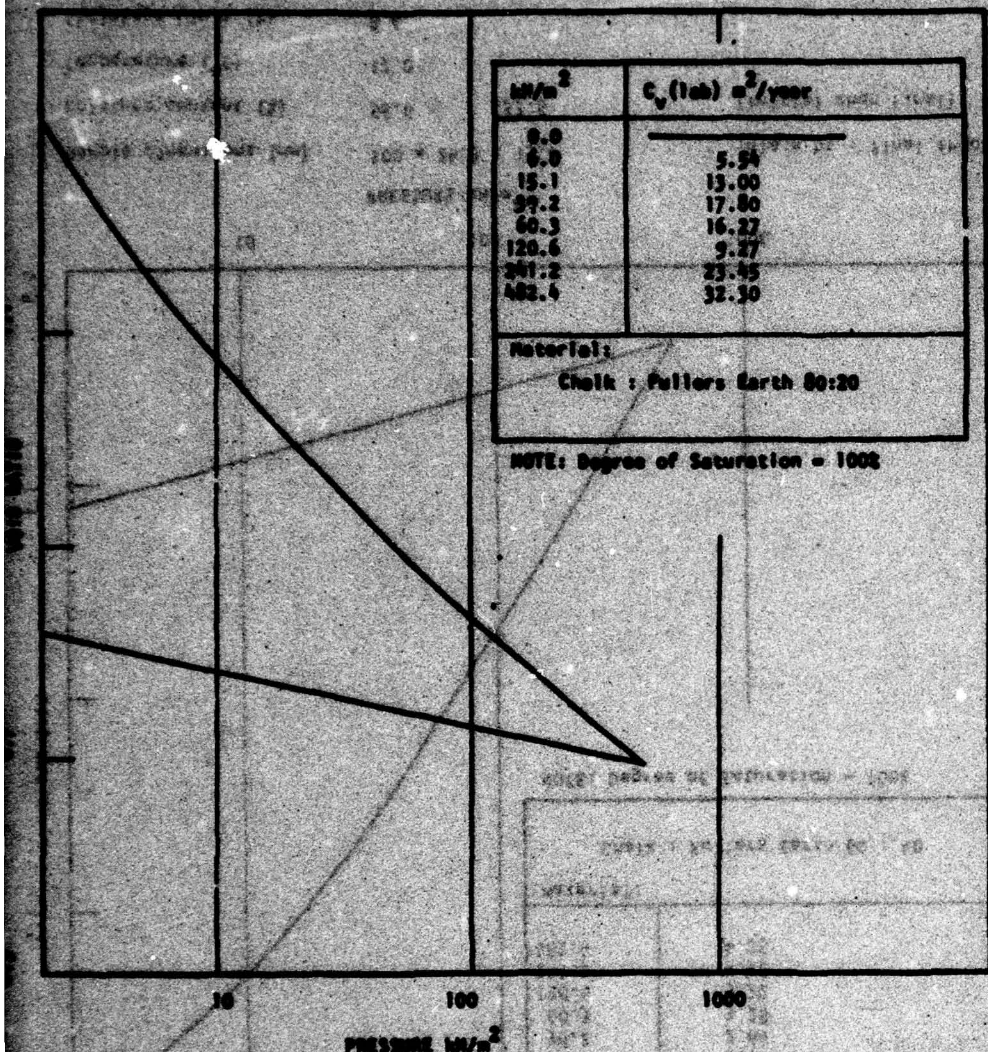
kN/m²	C_v(lab) m²/year
0.0	
6.0	3.79
15.1	7.29
30.2	5.20
60.3	8.27
120.6	9.03
241.2	8.88
482.4	3.67

Material:
Chalk : Fullers Earth 90:10

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 17.0 : 13.0		(dia x ht : final thick
Moisture content (%)	51.6	22.2	(initial then final)
Temperature (°C)	17.0		
Shrinkage Limit (%)			
Initial void ratio:	1.440		
Oc:	0.196		

CP3



kN/m²	C_v(lab) m²/year
0.0	—
6.0	5.54
15.1	13.00
30.2	17.80
60.3	16.27
120.6	9.27
241.2	23.45
482.4	32.30

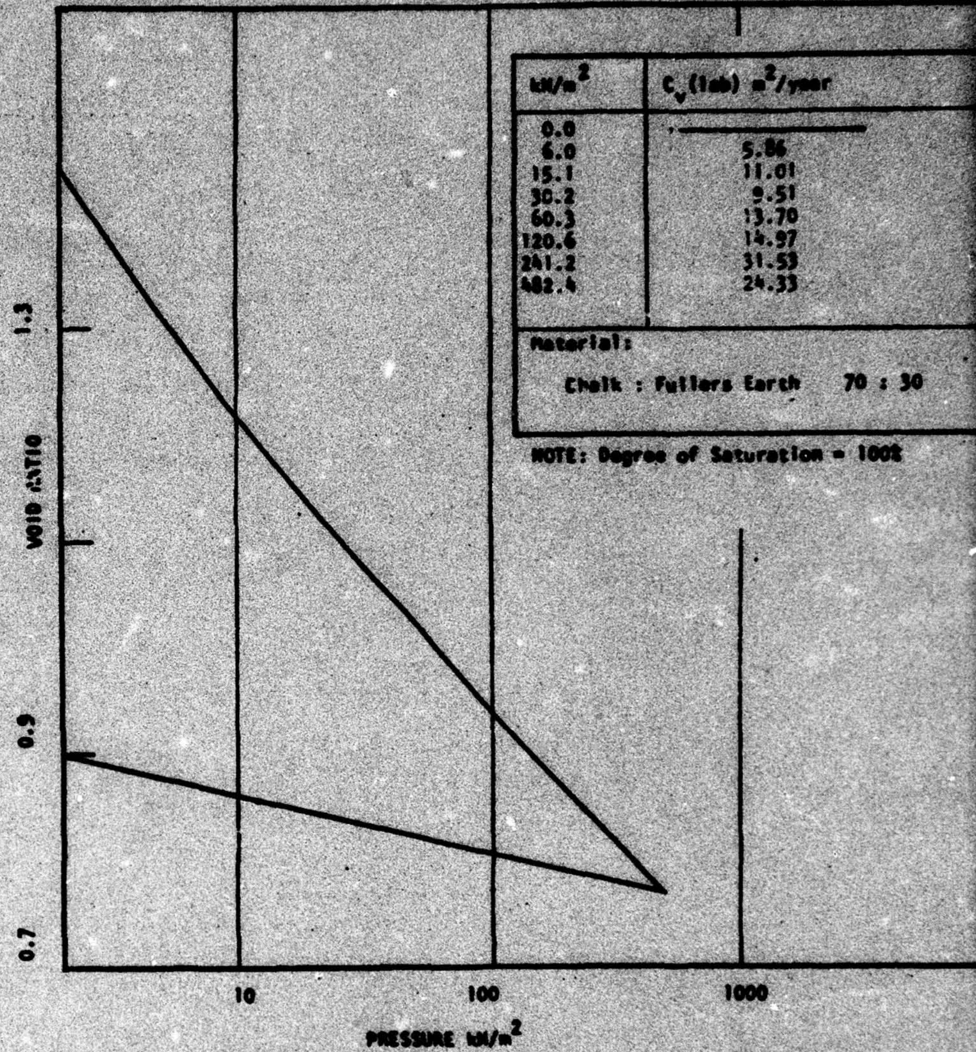
Material:

Chalk : Fullers Earth 80:20

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 22.7 : 17.0		(dia x ht : final thickness)
Moisture content (%)	52.0	28.9	(initial then final)
Temperature (°C)	17.0		
Shrinkage Limit (%)	3.6		
Initial void ratio:	1.455		
Oc:	0.210		

CP4



kN/m²	C_v(lab) m²/year
0.0	—
6.0	5.86
15.1	11.01
30.2	9.51
60.3	13.70
120.6	14.97
241.2	31.53
482.4	24.33

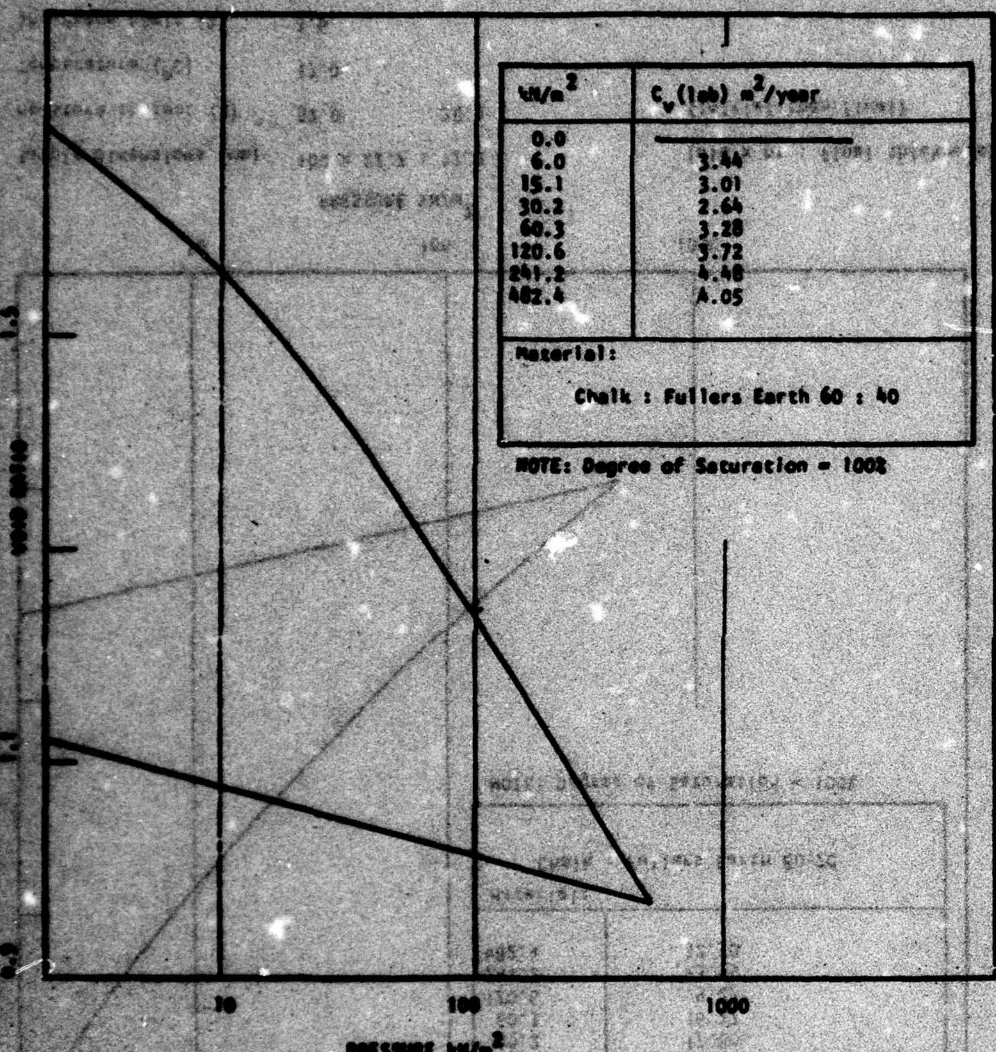
Material:

Chalk : Fullers Earth 70 : 30

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 22.9 : 17.0		(dia x ht : final thick
Moisture content (%)	54.9	31.8	(initial then final)
Temperature (°C)	17.0		
Shrinkage Limit (%)	3.9		
Initial void ratio:	1.574		
Oc:	0.250		

CF5



kN/m^2	C_v(lab) m^2/year
0.0	—
6.0	3.44
15.1	3.01
30.2	2.64
60.3	3.28
120.6	3.72
241.2	4.48
482.4	4.05

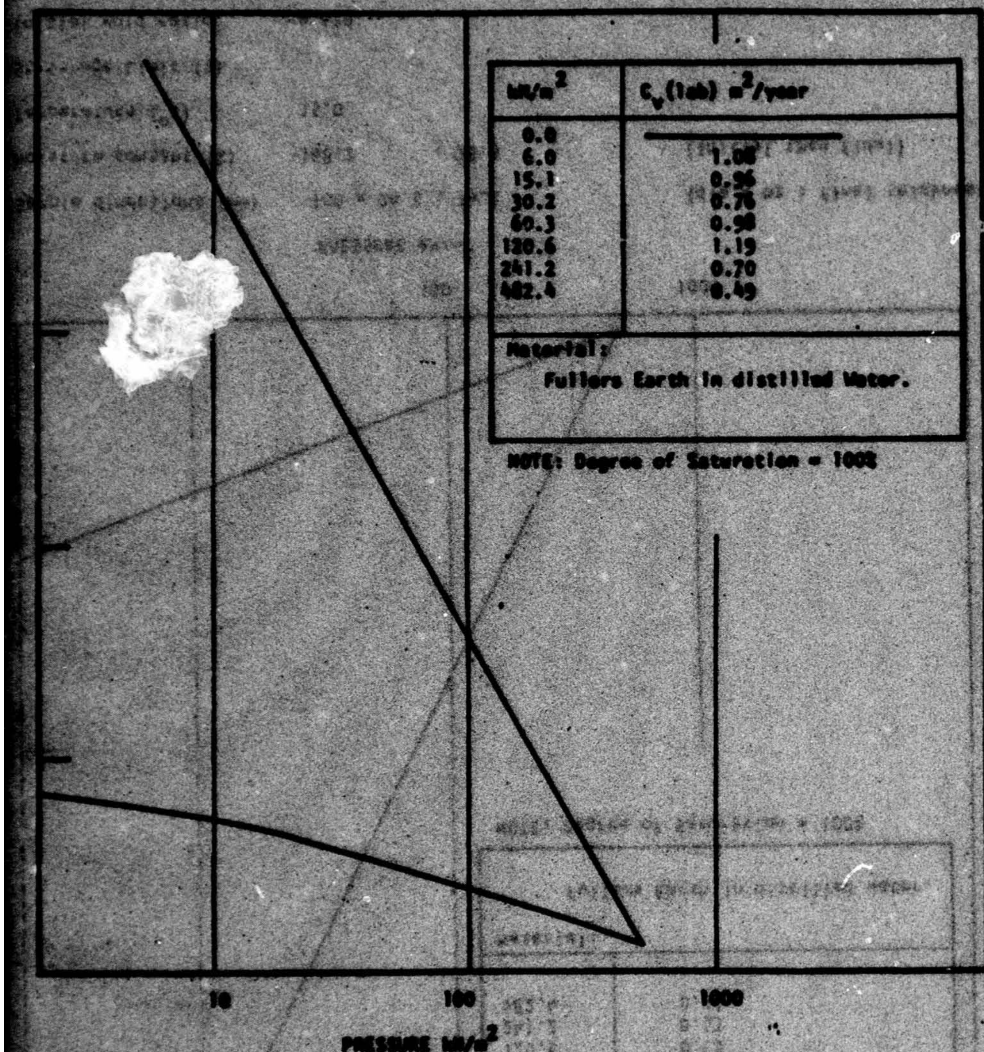
Material:

Chalk : Fullers Earth 60 : 40

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 24.3 : 19.0		(dia x ht : final thickness)
Moisture content (%)	56.6	37.5	(initial then final)
Temperature (^{o}C)	17.0		
Shrinkage Limit (%)	8.6		
Initial void ratio:	1.728		
Cc:	0.380		

FE 3 Cold



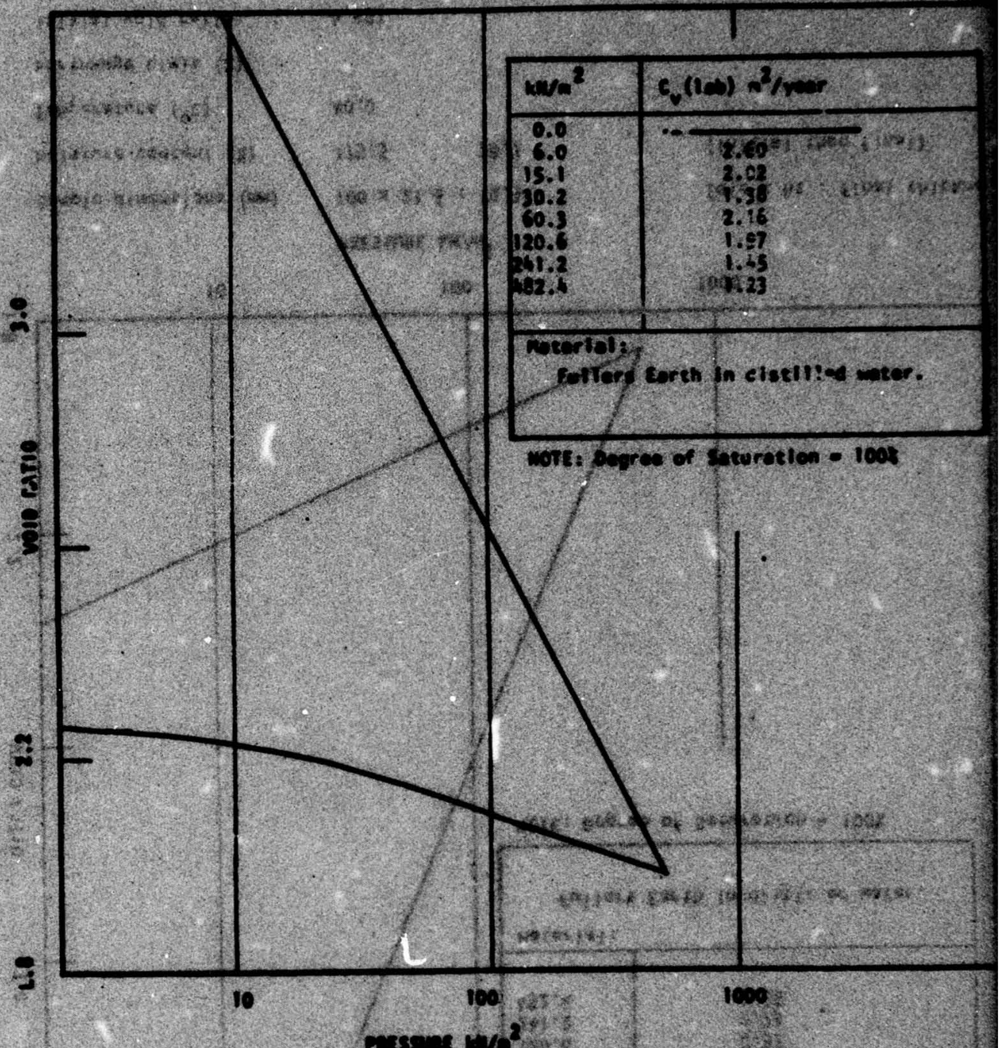
kN/m²	C_v(lab) m²/year
0.0	—
6.0	1.08
15.1	0.96
30.2	0.76
60.3	0.98
120.6	1.19
241.2	0.70
482.4	0.49

Material:
Fullers Earth in distilled Water.

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 25.4	: 12.0	(dia x ht : final thickness)
Moisture content (%)	212.0	59.3	(initial then final)
Temperature (°C)	15.0		
Shrinkage Limit (%)			
Initial void ratio:	4.590		
Cc:	0.85		

FE3 Hot



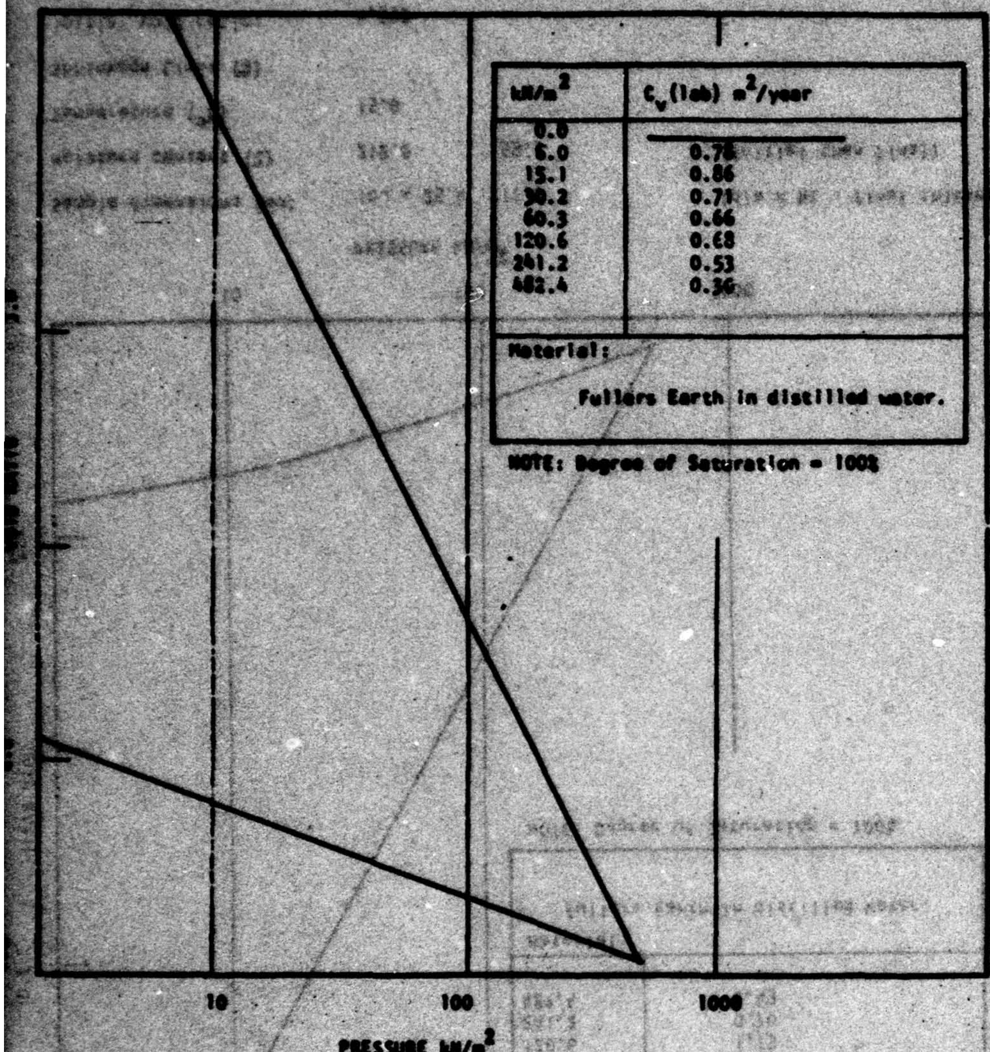
kN/m²	C_v(lab) m²/year
0.0	—
6.0	2.60
15.1	2.02
30.2	1.38
60.3	2.16
120.6	1.97
241.2	1.45
482.4	1.23

Material:
Fullers Earth in distilled water.

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 25.4	: 12.5	(dia x ht : final thick
Moisture content (%)	212.0	66.7	(initial then final)
Temperature (°C)	50.0		
Shrinkage Limit (%)			
Initial void ratio:	4.800		
Cc:	0.97		

FE4a Cold



kN/m²	C_v(lab) m²/year
0.0	—
6.0	0.78
15.1	0.86
30.2	0.71
60.3	0.66
120.6	0.68
241.2	0.53
482.4	0.36

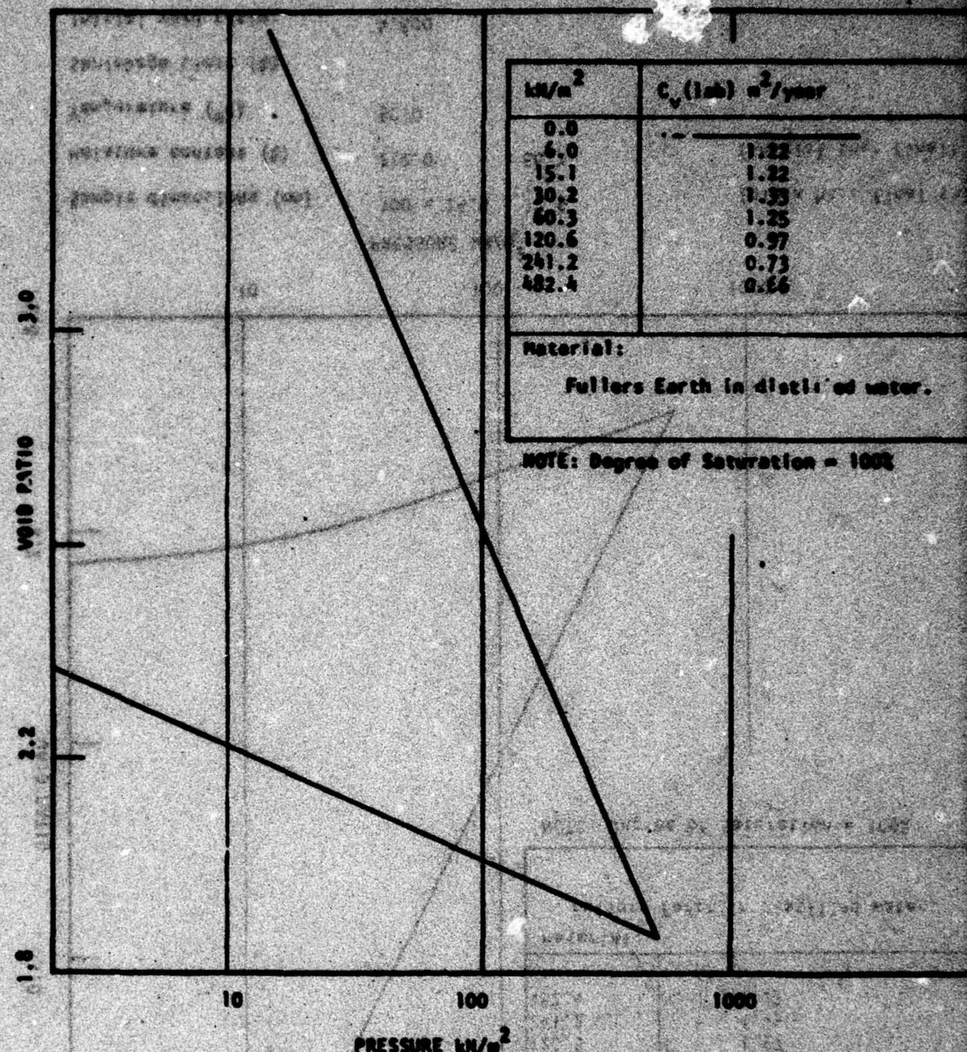
Material:

Fullers Earth in distilled water.

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 24.8 : 14.2		(dia x ht : final thickness)
Moisture content (%)	168.2	: 78.3	(initial then final)
Temperature (°C)	15.0		
Shrinkage Limit (%)			
Initial void ratio:	4.639		
Oc:	0.95		

FE4a Hot



kN/m²	C_v(lab) m²/year
0.0	—
6.0	1.22
15.1	1.22
30.2	1.35
60.3	1.25
120.6	0.97
241.2	0.73
482.4	0.66

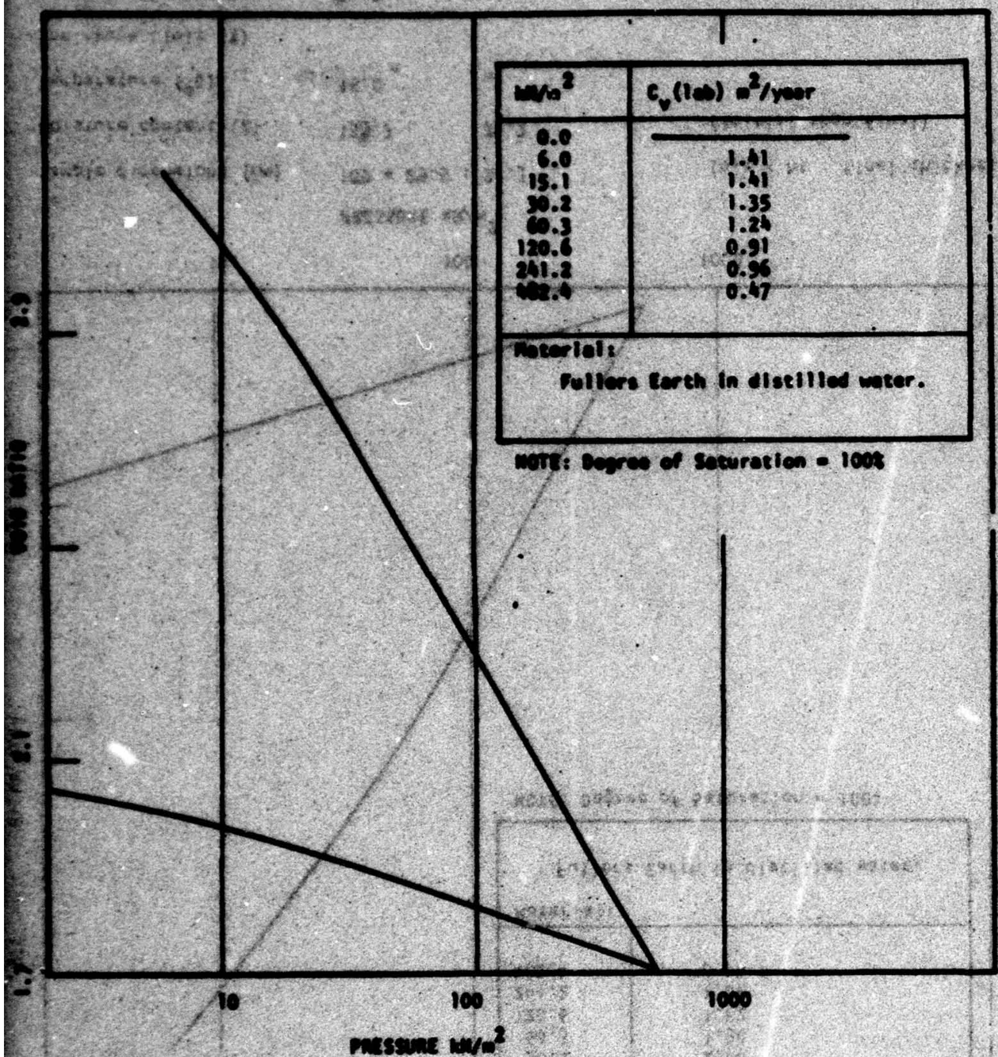
Material:

Fullers Earth in distilled water.

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 21.6 : 12.3		(dia x ht : final thick
Moisture content (%)	175.5	78.7	(initial then final)
Temperature (°C)	40.0		
Shrinkage Limit (%)			
Initial void ratio:	4.957		
Oc:	1.11		

FES Cold



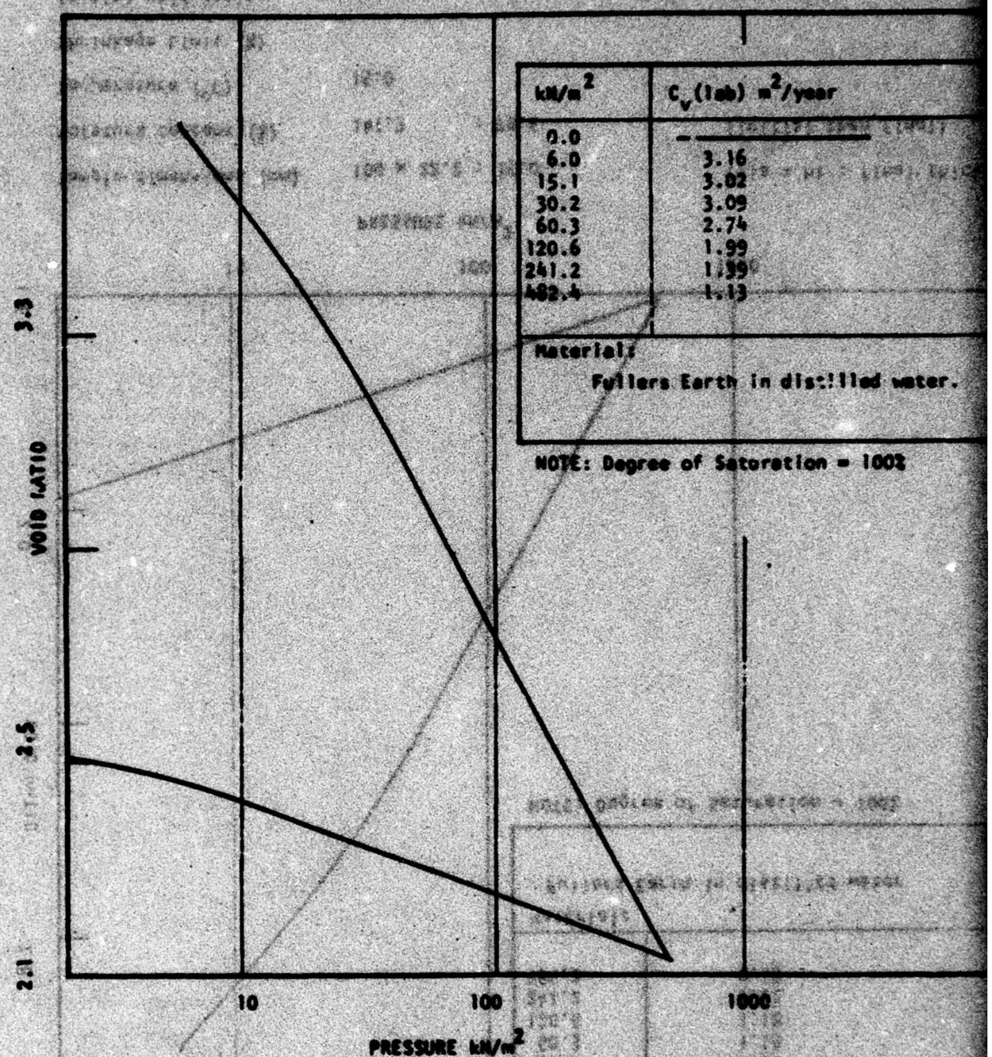
kN/m²	C_v(lab) m²/year
0.0	—
6.0	1.41
15.1	1.41
30.2	1.35
60.3	1.24
120.6	0.91
241.2	0.96
482.4	0.47

Material:
Fullers Earth in distilled water.

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 23.6 : 14.5	(dia x ht : final thickness)
Moisture content (%)	162.C	(initial then final)
Temperature (°C)	15.0	
Shrinkage Limit (%)		
Initial void ratio:	4.041	
Oc:	0.830	

FE 5 Hot



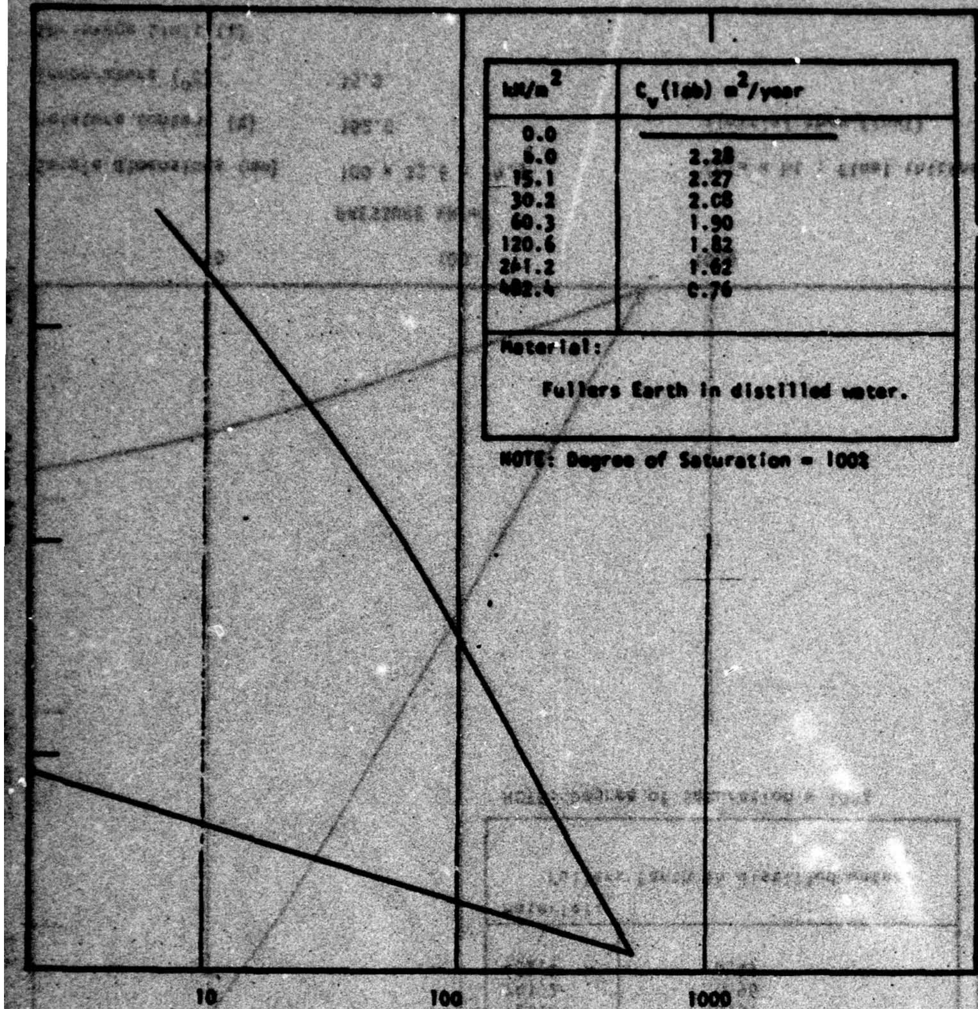
kN/m²	C_v(lab) m²/year
0.0	—
6.0	3.16
15.1	3.02
30.2	3.09
60.3	2.74
120.6	1.99
241.2	1.39
482.4	1.13

Material:
Fullers Earth in distilled water.

NOTE: Degree of Saturation = 100%

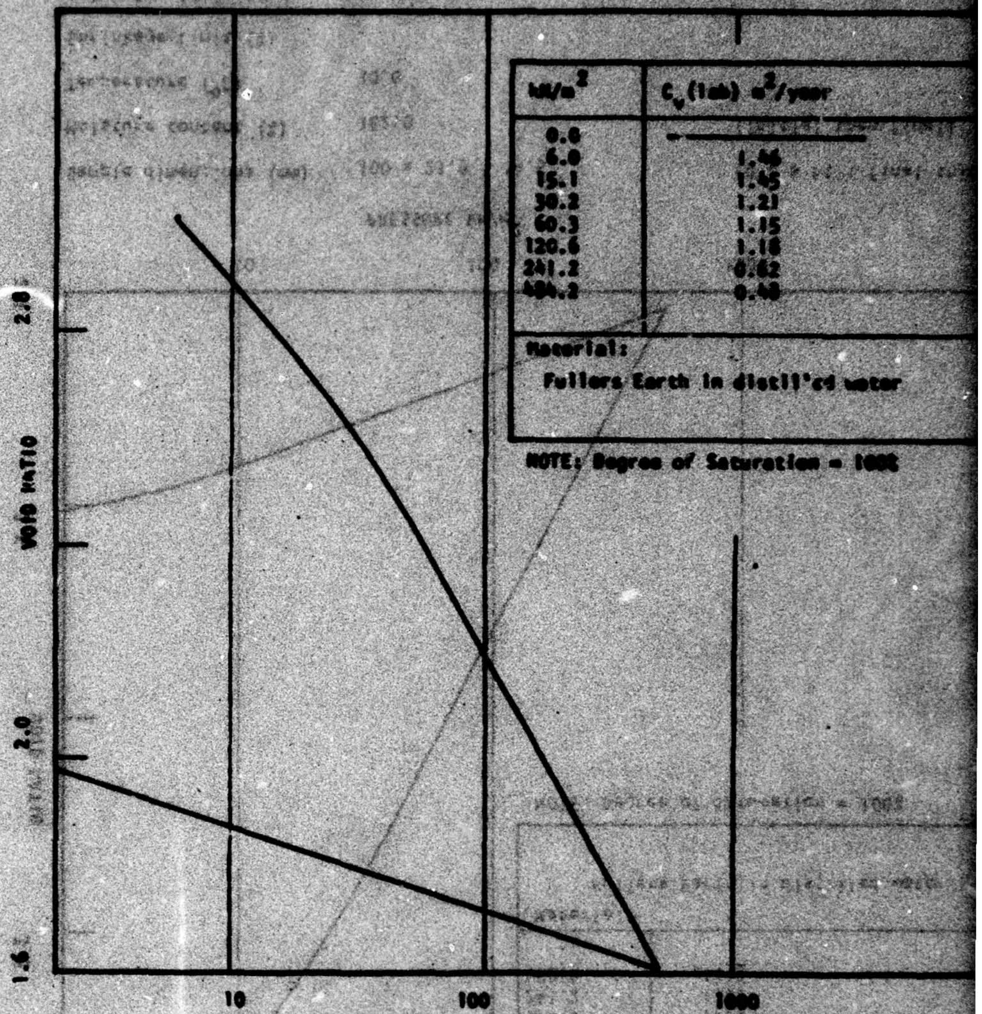
Sample dimensions (mm)	100 x 21.9 : 14.5	(dia x ht : final thic
Moisture content (%)	162.0	(initial then final)
Temperature (°C)	30.0	
Shrinkage Limit (%)	-	
Initial void ratio:	4.37	
Oc:	0.875	

FE6 Cold



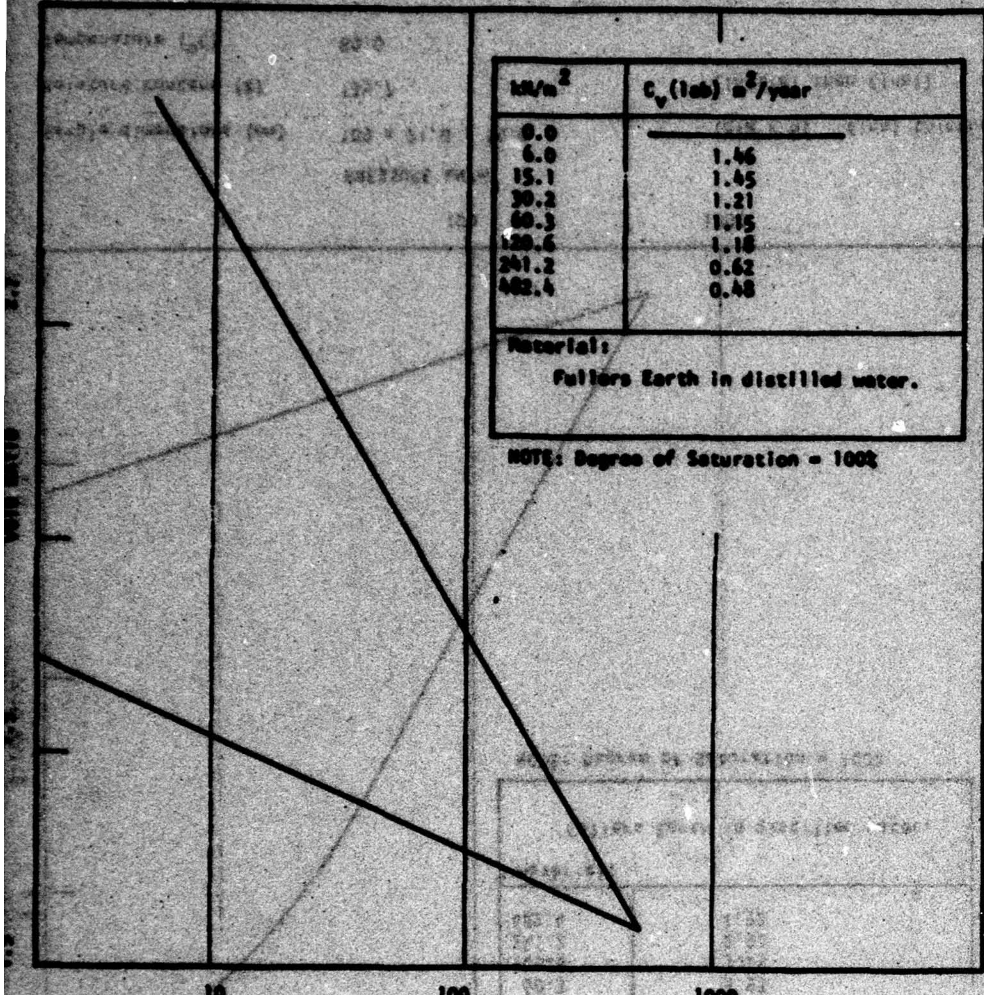
Sample dimensions (mm)	100 x 29.5 : 21.3		(dia x ht : final thickness)
Moisture content (%)	139.7	71.7	(initial then final)
Temperature (^{o}C)	15.0		
Shrinkage Limit (%)			
Initial void ratio:	21.3		
Oc:	0.830		

FE6 Nat



Sample dimensions (mm)	100 x 22.2 : 15.0	(dia x ht : final thic
Moisture content (%)	141.7 : 70.6	(initial then final)
Temperature (^{o}C)	15.0	
Shrinkage Limit (%)		
Initial void ratio:	3.497	
Oc:	0.845	

FEB Cold

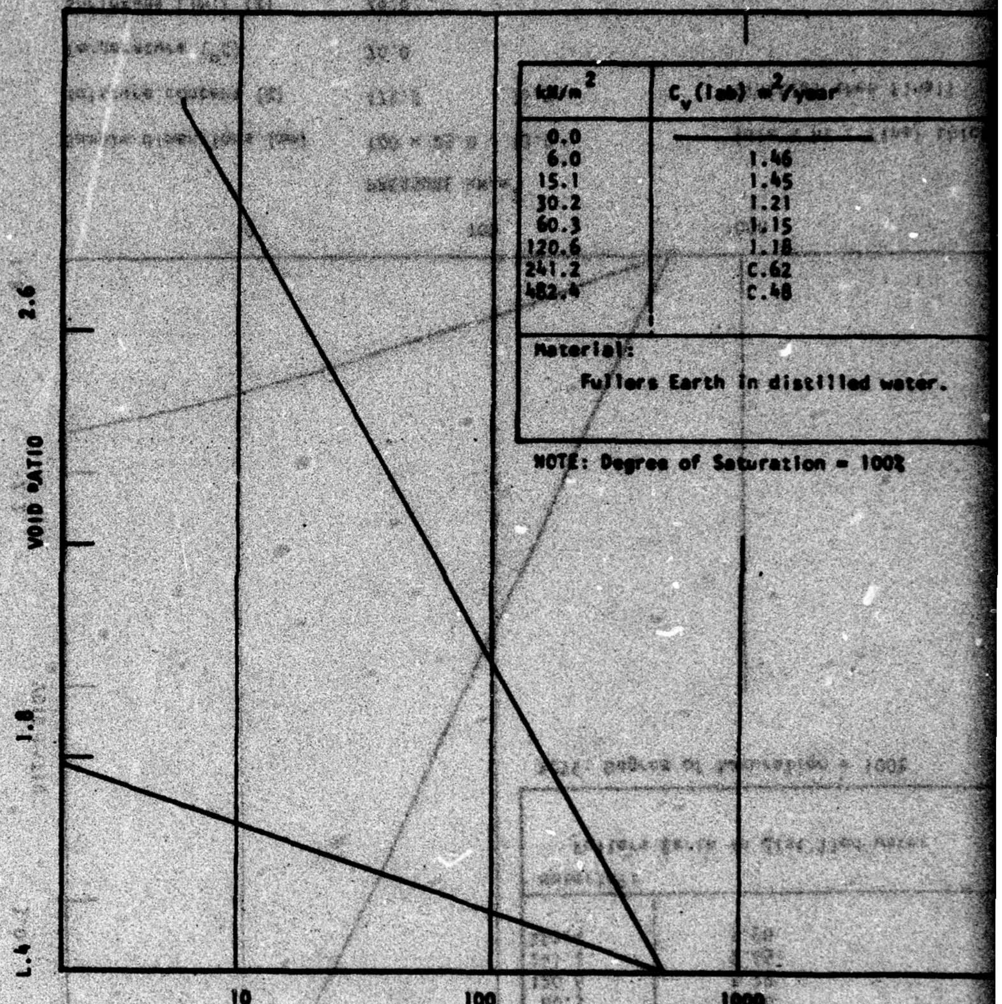


kN/m^2	C_v(lab) m^2/year
0.0	
6.0	1.46
15.1	1.45
30.2	1.21
60.3	1.15
120.6	1.18
241.2	0.62
482.4	0.48

Material:
Fullers Earth in distilled water.

Sample dimensions (mm)	100 x 22.2 : 15.0	(dia x ht : final thickness)
Moisture content (%)	141.7 : 70.6	(initial then final)
Temperature (°C)	15.0	
Shrinkage Limit (%)		
Initial void ratio:	3.497	
Oc:	0.845	

FEB Hot

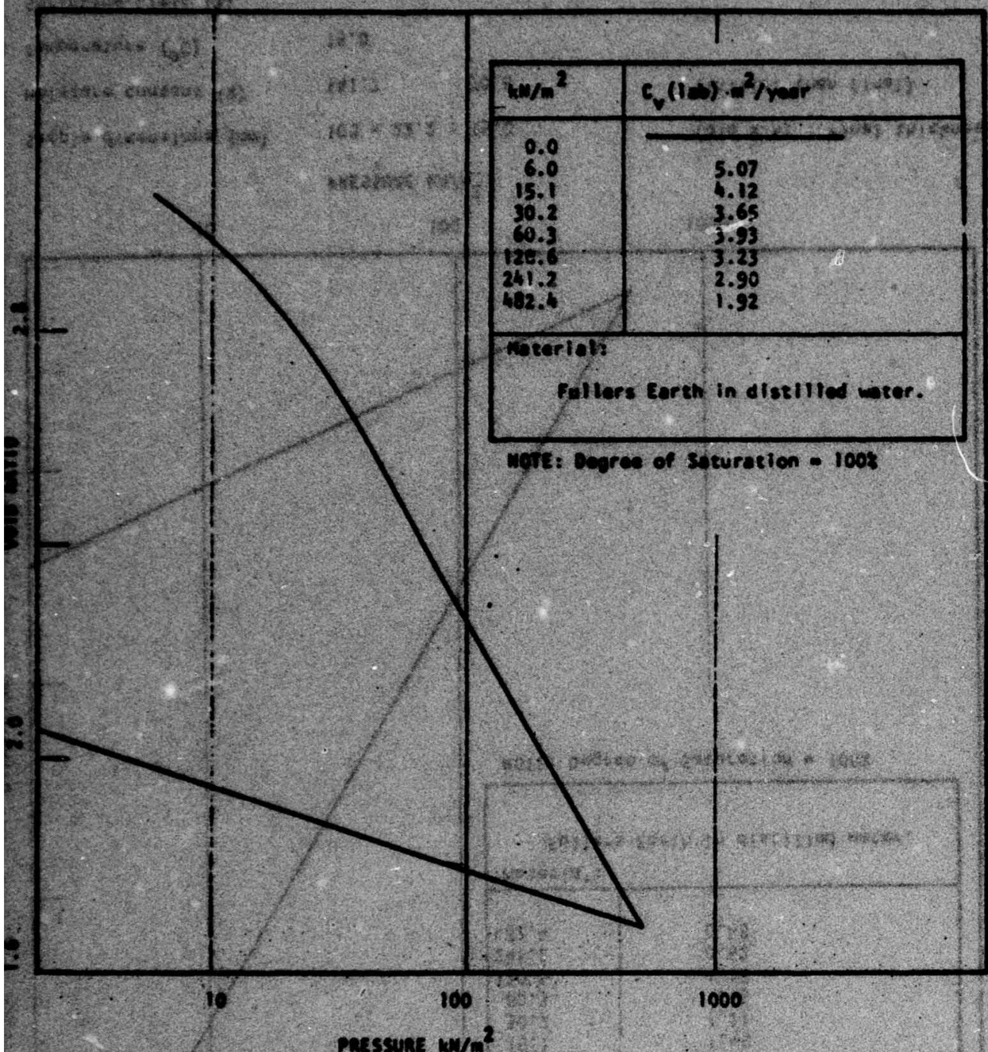


kN/m^2	C_v(lab) m^2/year
0.0	
6.0	1.46
15.1	1.45
30.2	1.21
60.3	1.15
120.6	1.18
241.2	C.62
482.4	C.48

Material:
Fullers Earth in distilled water.

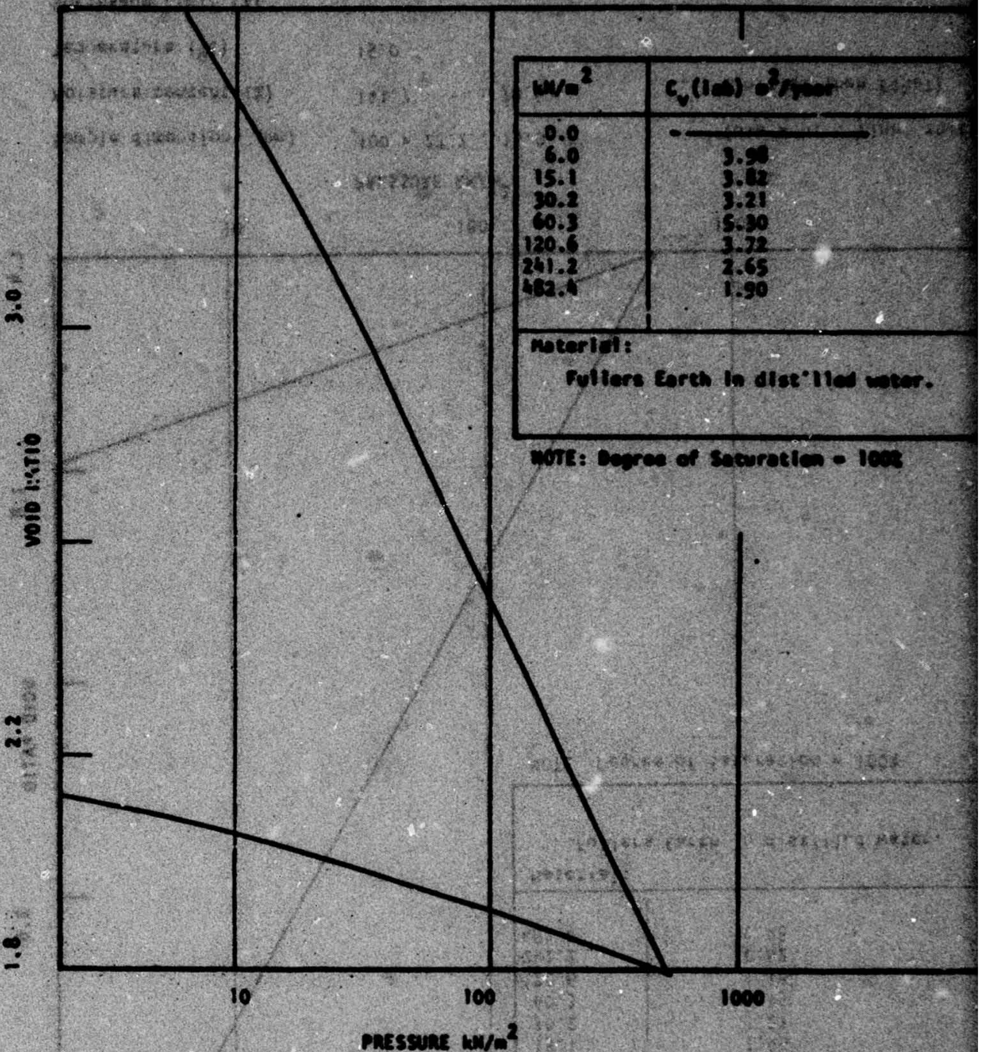
Sample dimensions (mm)	100 x 22.2 : 15.0	(dia x ht : final thick
Moisture content (%)	141.7 : 70.6	(initial then final)
Temperature (°C)	15.0	
Shrinkage Limit (%)		
Initial void ratio:	3.497	
Oc:	0.845	

FE9



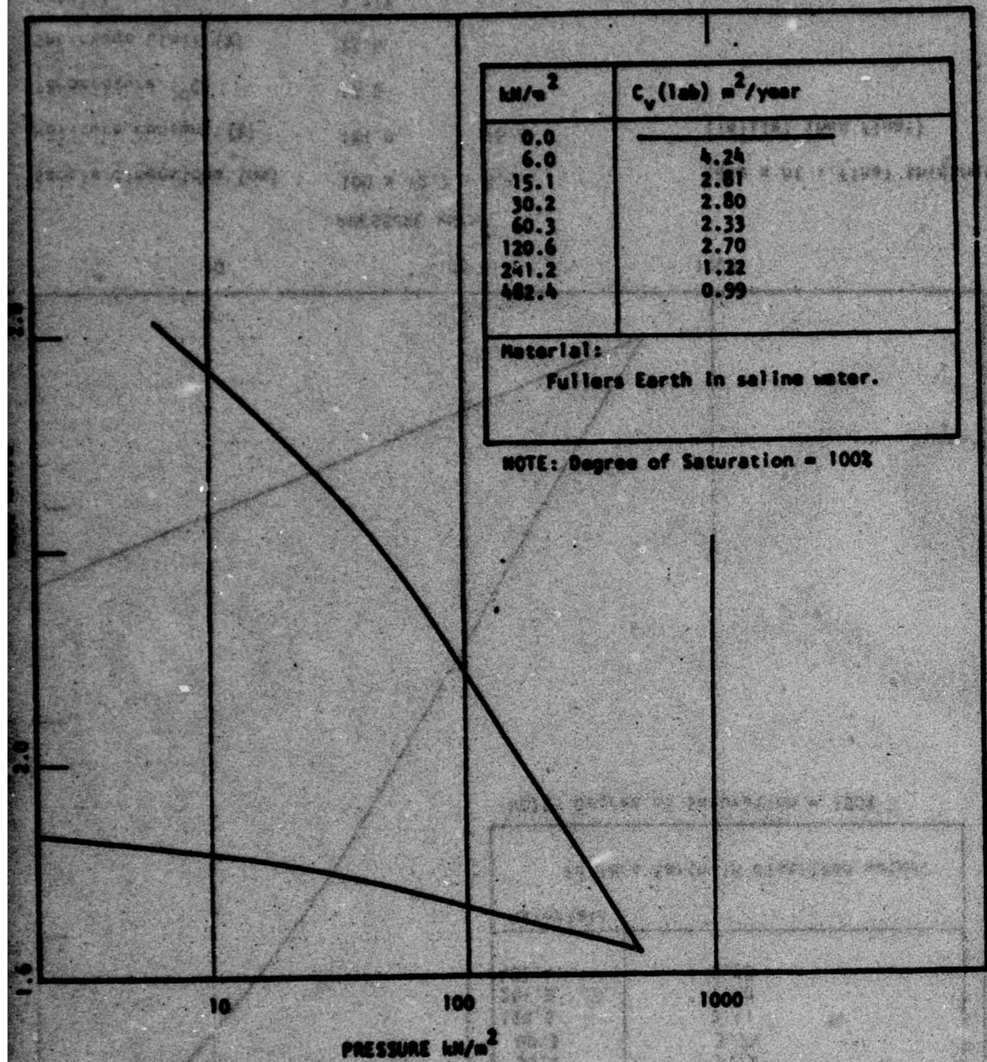
Sample dimensions (mm)	100 x 21.0 : 15.0	(dia x ht : final thickness)
Moisture content (%)	135.7	(initial then final)
Temperature (°C)	60.0	
Shrinkage Limit (%)		
Initial void ratio:	3.423	
Cc:	0.83	

FE 10



Sample dimensions (mm)	100 x 25.0 : 13.0		(dia x ht : final thic
Moisture content (%)	173.3	76.9	(initial then final)
Temperature (°C)	70.0		
Shrinkage Limit (%)	28.6		
Initial void ratio:	4.356		
Cc:	1.02		

FE14



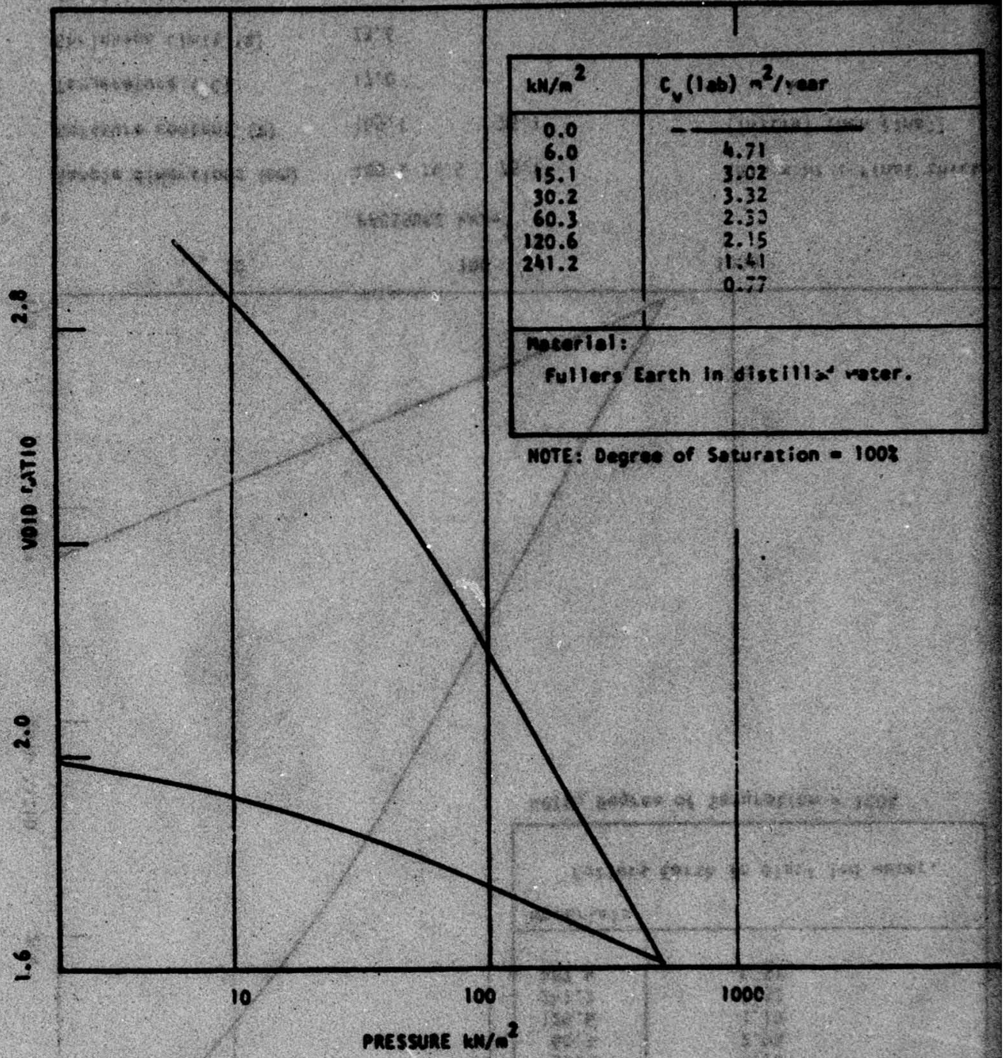
kN/m²	C_v(lab) m²/year
0.0	—
6.0	4.24
15.1	2.81
30.2	2.80
60.3	2.33
120.6	2.70
241.2	1.22
482.4	0.99

Material:
Fullers Earth in saline water.

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 20.6 : 14.5		(dia x ht : final thickness)
Moisture content (%)	117.1	69.1	(initial then final)
Temperature (°C)	17.0		
Shrinkage Limit (%)	21.4		
Initial void ratio:	3.126		
Oc:	0.750		

FE 15



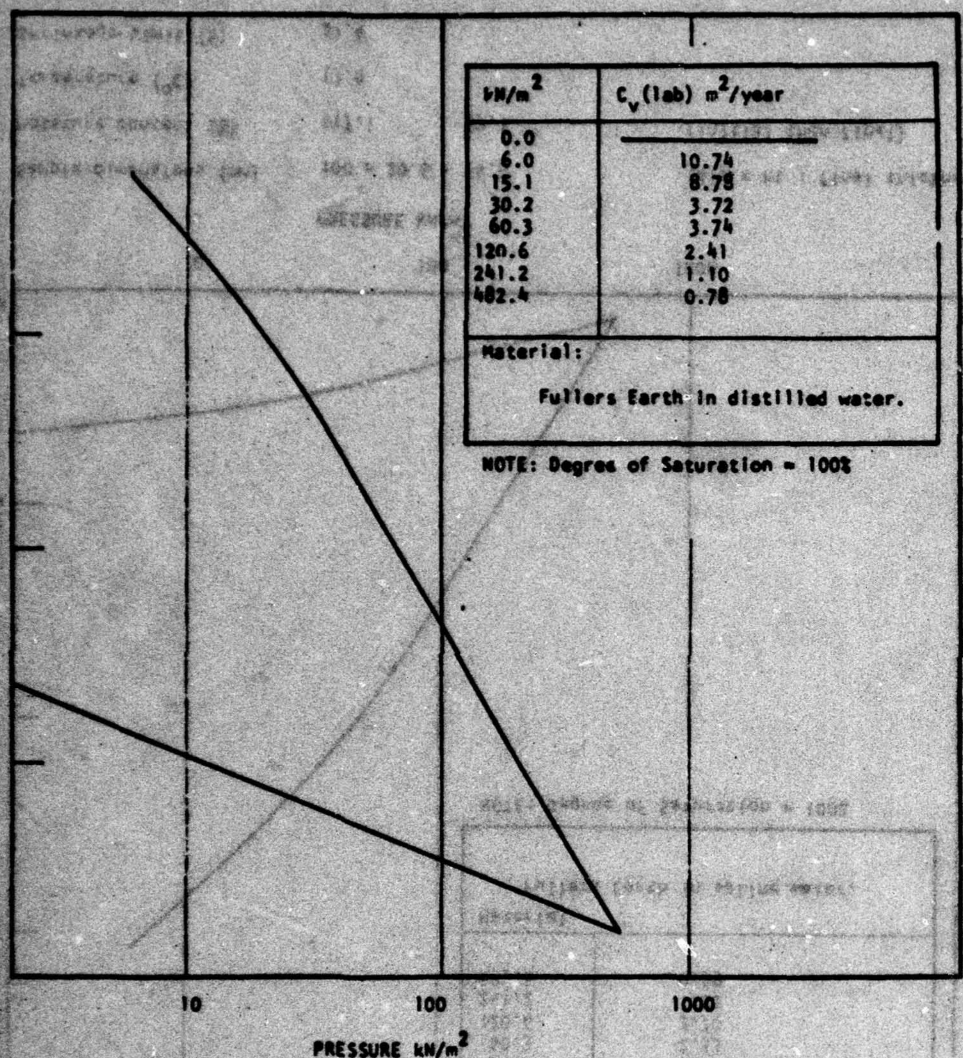
kN/m²	C_v(lab) m²/year
0.0	—
6.0	4.71
15.1	3.02
30.2	3.32
60.3	2.30
120.6	2.15
241.2	1.41
	0.77

Material:
Fullers Earth in distilled water.

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 22.4 : 15.5		(dia x ht : final thickness)
Moisture content (%)	97.1	74.1	(initial then final)
Temperature (°C)	20.0		
Shrinkage Limit (%)	25.0		
Initial void ratio:	3.407		
Oc:	0.805		

FE 17



kN/m²	C_v(lab) m²/year
0.0	—
6.0	10.74
15.1	8.78
30.2	3.72
60.3	3.74
120.6	2.41
241.2	1.10
482.4	0.78

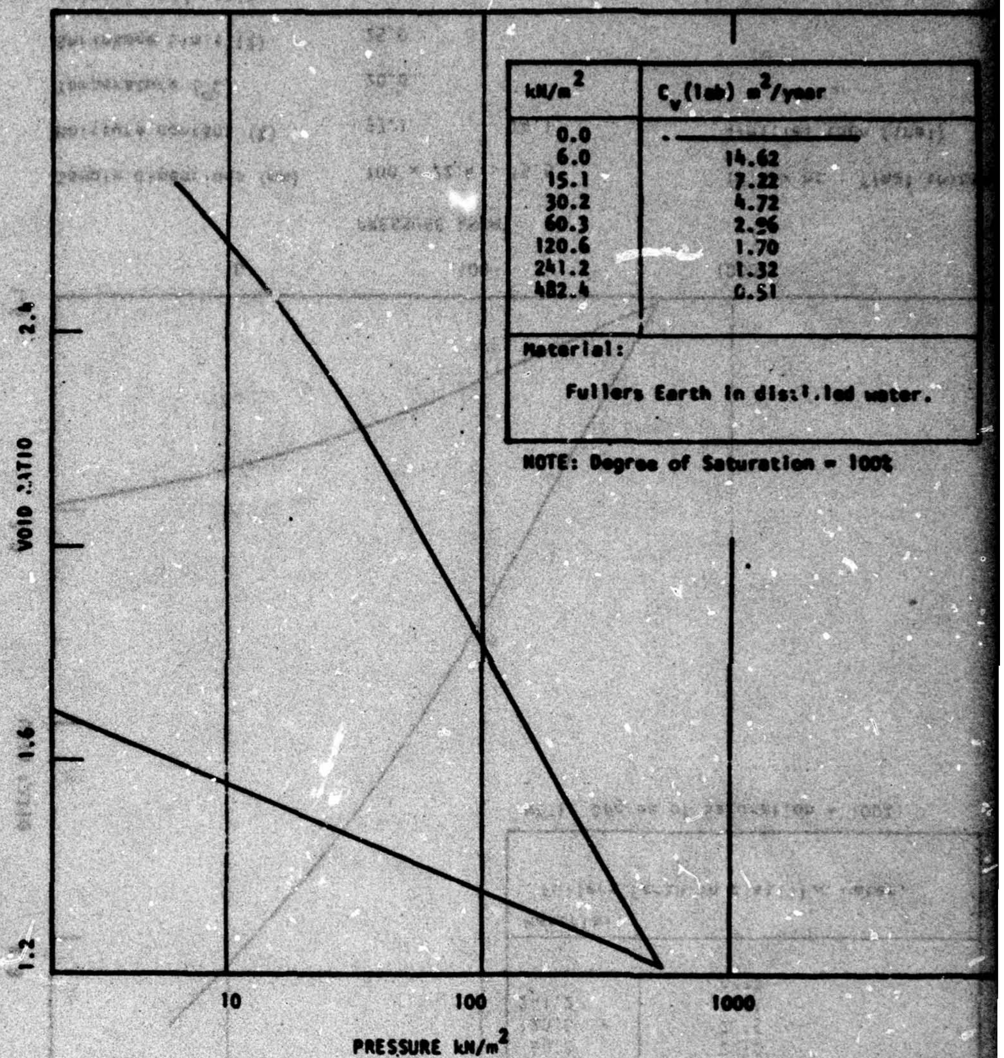
Material:

Fullers Earth in distilled water.

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 12.7 : 8.5		(dia x ht : final thickness)
Moisture content (%)	181.0	76.8	(initial then final)
Temperature (°C)	17.0		
Shrinkage Limit (%)	23.6		
Initial void ratio:	3.218		
Gc:	0.854		

FE 18



kN/m²	C_v(lab) m²/year
0.0	—
6.0	14.62
15.1	7.22
30.2	4.72
60.3	2.96
120.6	1.70
241.2	1.32
482.4	0.51

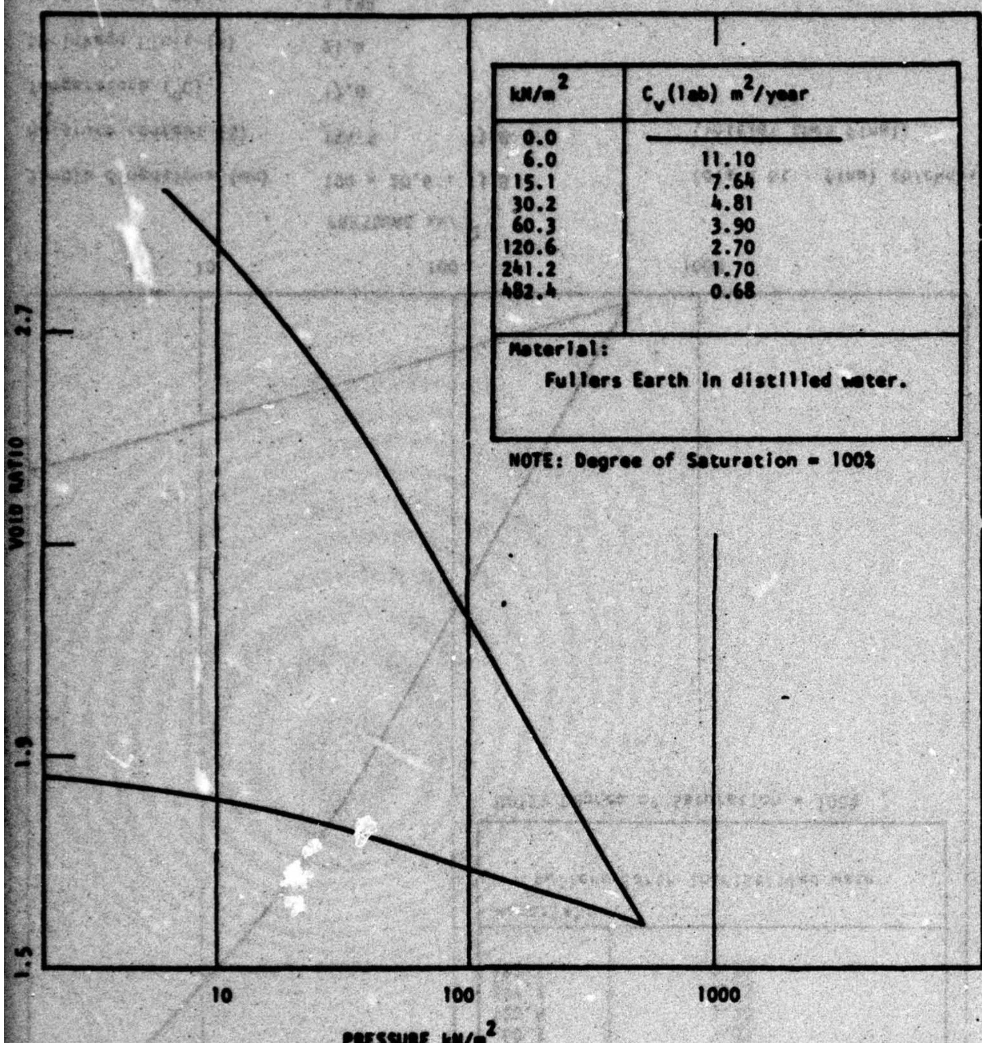
Material:

Fullers Earth in distilled water.

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 14.5 : 75.1		(dia x ht : final thickness)
Moisture content (%)	169.1	75.1	(initial then final)
Temperature (°C)	17.0		
Shrinkage Limit (%)	23.6		
Initial void ratio:	3.420		
Gc:	0.855		

FE19

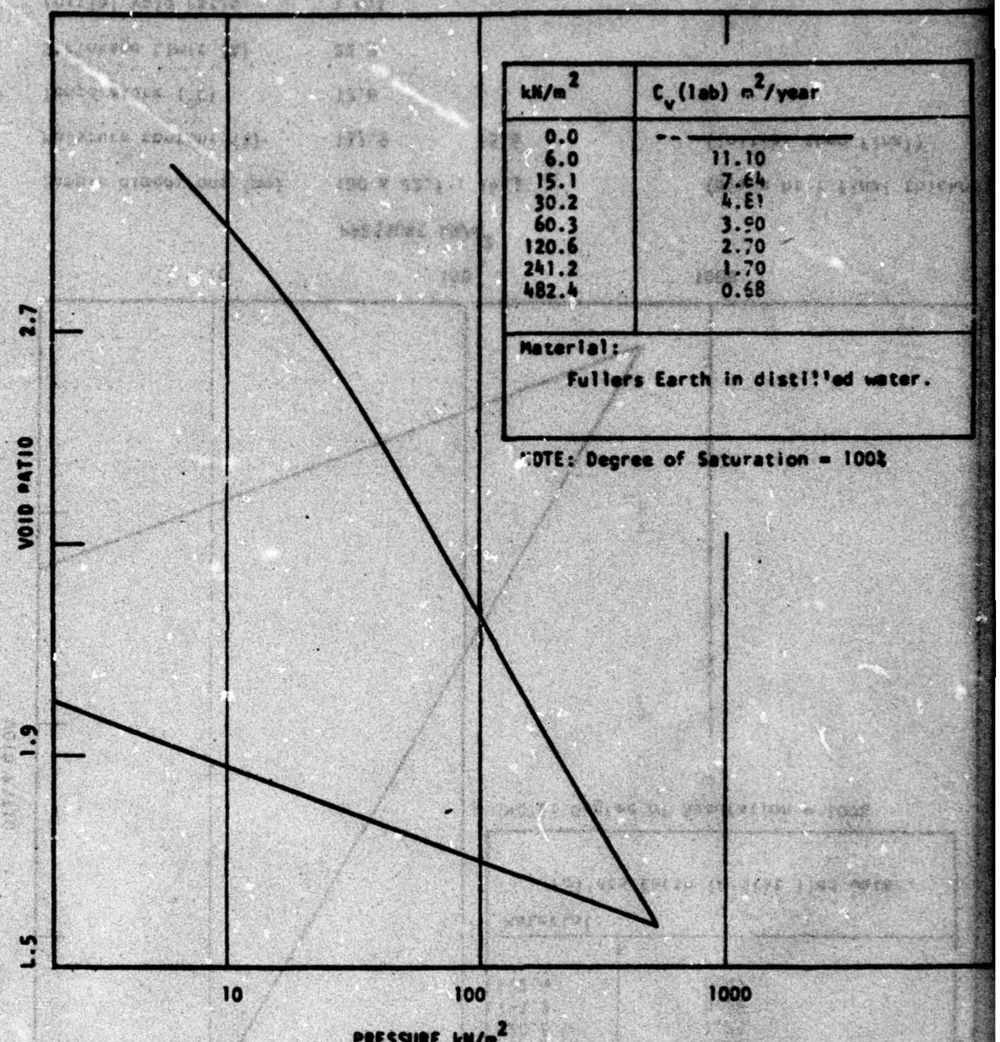


kN/m^2	C_v(lab) m^2/year
0.0	
6.0	11.10
15.1	7.64
30.2	4.81
60.3	3.90
120.6	2.70
241.2	1.70
482.4	0.68

Material:
Fullers Earth in distilled water.

Sample dimensions (mm)	100 x 19.8 : 13.0		(dia x ht : final thickness)
Moisture content (%)	160.6		(initial then final)
Temperature (^{o}C)	17.0		
Shrinkage Limit (%)	23.6		
Initial void ratio:	3.397		
Oc:	0.820		

FE 20

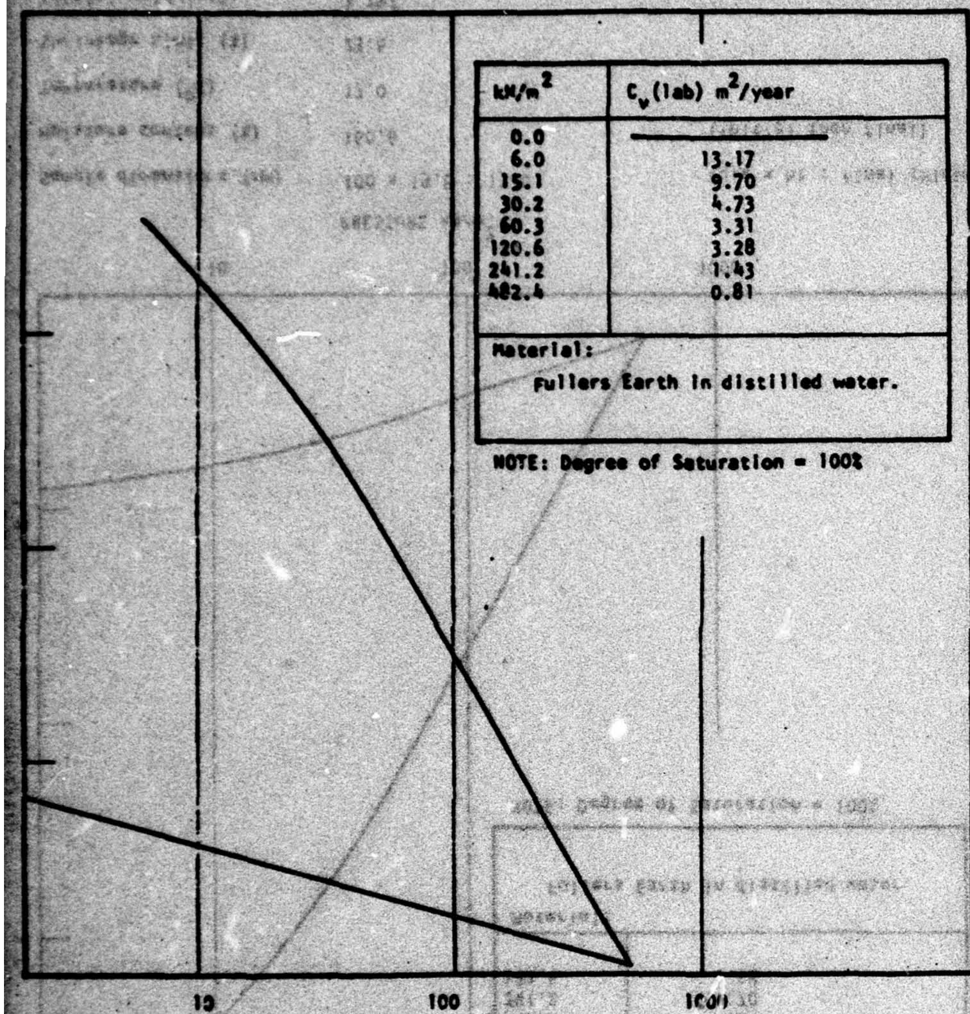


kN/m^2	C_v(lab) m^2/year
0.0	--
6.0	11.10
15.1	7.64
30.2	4.81
60.3	3.90
120.6	2.70
241.2	1.70
482.4	0.68

Material:
Fullers Earth in distilled water.

Sample dimensions (mm)	100 x 19.8 : 13.0		(dia x ht : final thickness)
Moisture content (%)	160.6	72.3	(initial then final)
Temperature (^{o}C)	17.0		
Shrinkage Limit (%)	23.6		
Initial void ratio:	3.397		
Oc:	0.820		

FE 21



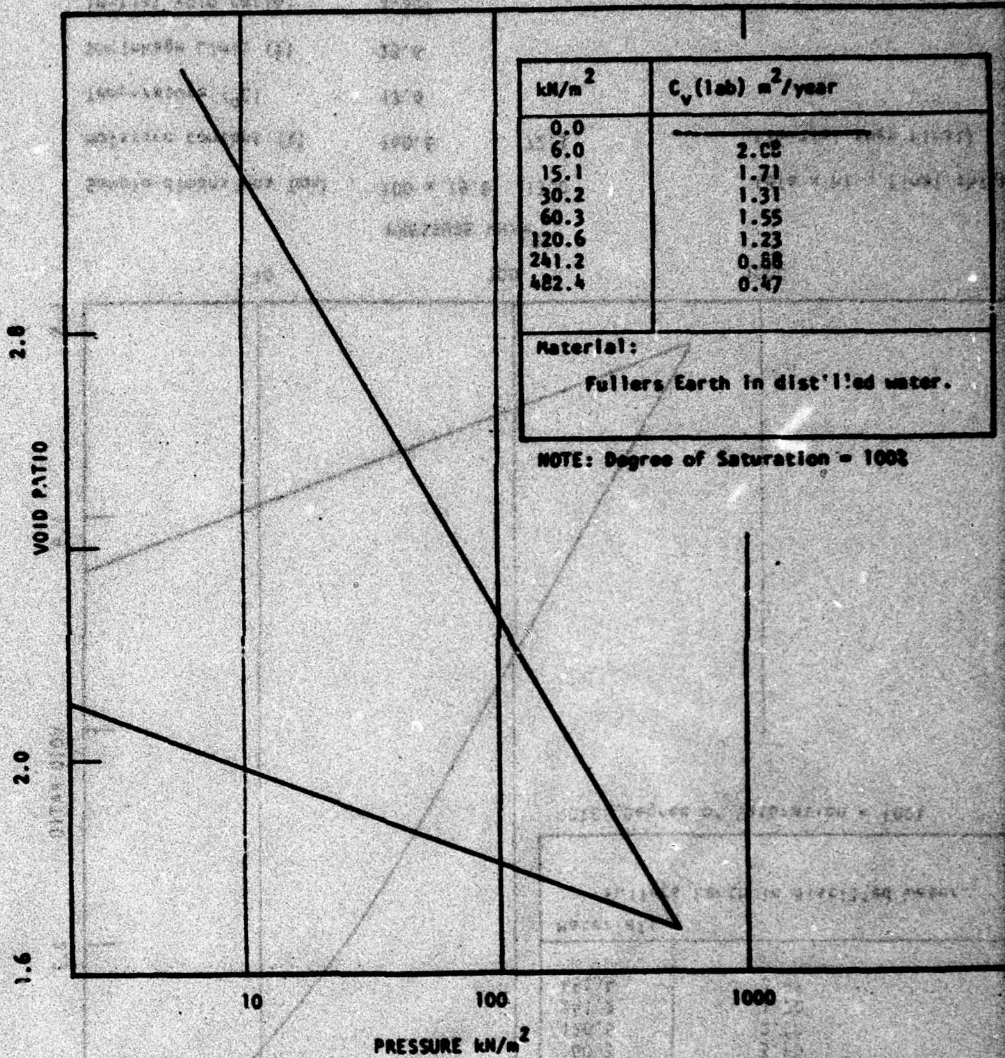
kN/m²	C_v(lab) m²/year
0.0	—
6.0	13.17
15.1	9.70
30.2	4.73
60.3	3.31
120.6	3.28
241.2	1.43
482.4	0.81

Material:
Fullers Earth in distilled water.

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 20.6 : 13.8		(dia x ht : final thickness)
Moisture content (%)	154.5	73.8	(initial then final)
Temperature (°C)	17.0		
Shrinkage Limit (%)	21.4		
Initial void ratio:	3.488		
Oc:	0.845		

FE23



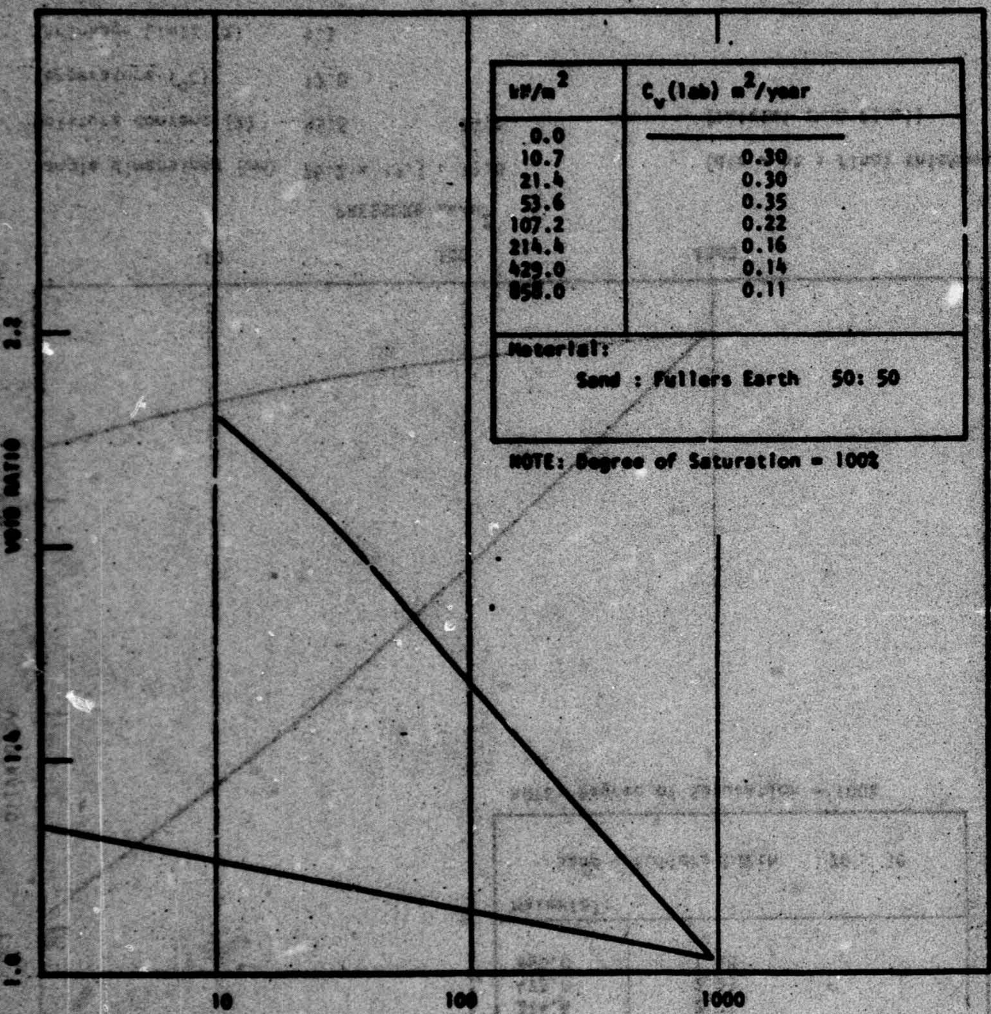
kN/m²	C_v(lab) m²/year
0.0	—
6.0	2.08
15.1	1.71
30.2	1.31
60.3	1.55
120.6	1.23
241.2	0.88
482.4	0.47

Material:
Fullers Earth in distilled water.

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	100 x 22.1 : 14.5		(dia x ht : final thickness)
Moisture content (%)	137.9	75.6	(initial then final)
Temperature (°C)	17.0		
Shrinkage Limit (%)	22.9		
Initial void ratio:	3.821		
Oc:	0.853		

S1



kN/m²	C_v(lab) m²/year
0.0	—
10.7	0.30
21.4	0.30
53.6	0.35
107.2	0.22
214.4	0.16
429.0	0.14
858.0	0.11

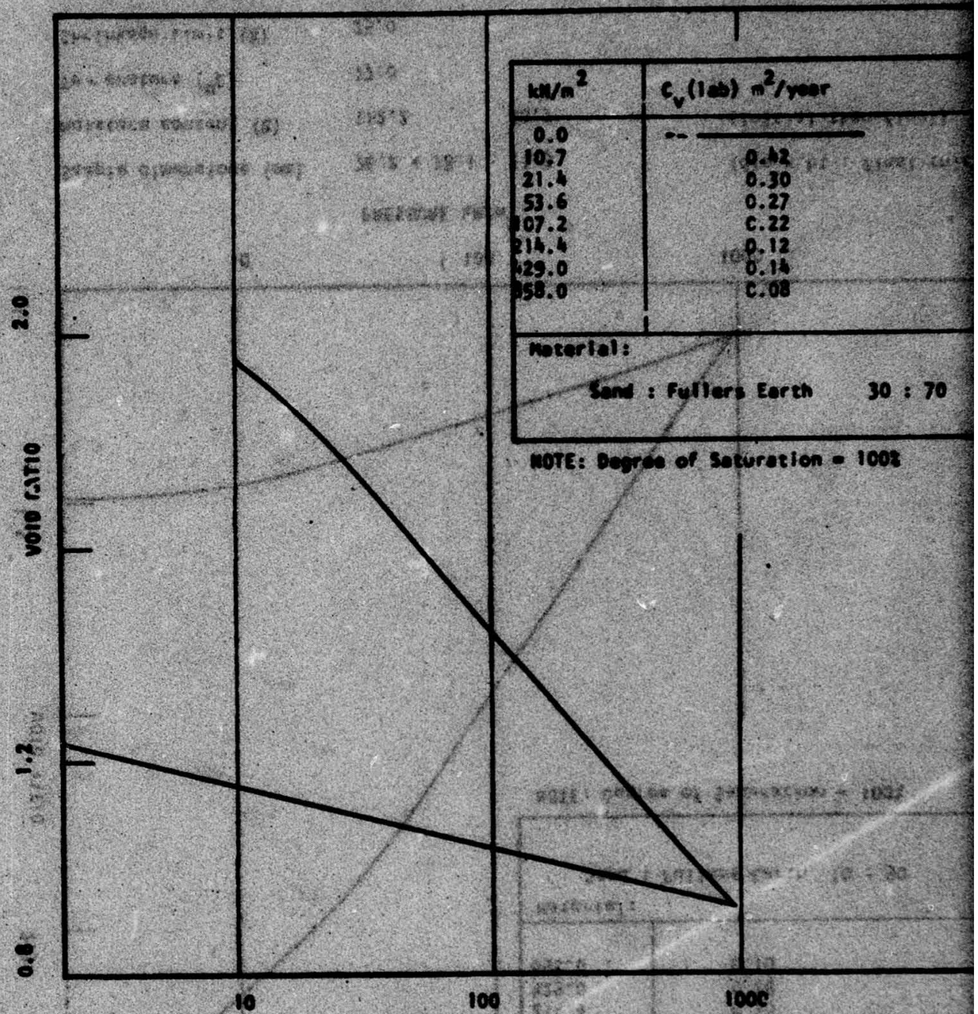
Material:

Sand : Fullers Earth 50: 50

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	76.2 x 18.2 : 13.0		(dia x ht : final thickness)
Moisture content (%)	57.7	34.4	(initial then final)
Temperature (°C)	17.0		
Shrinkage Limit (%)	12.1		
Initial void ratio:	2.256		
Oc:	0.545		

S 2



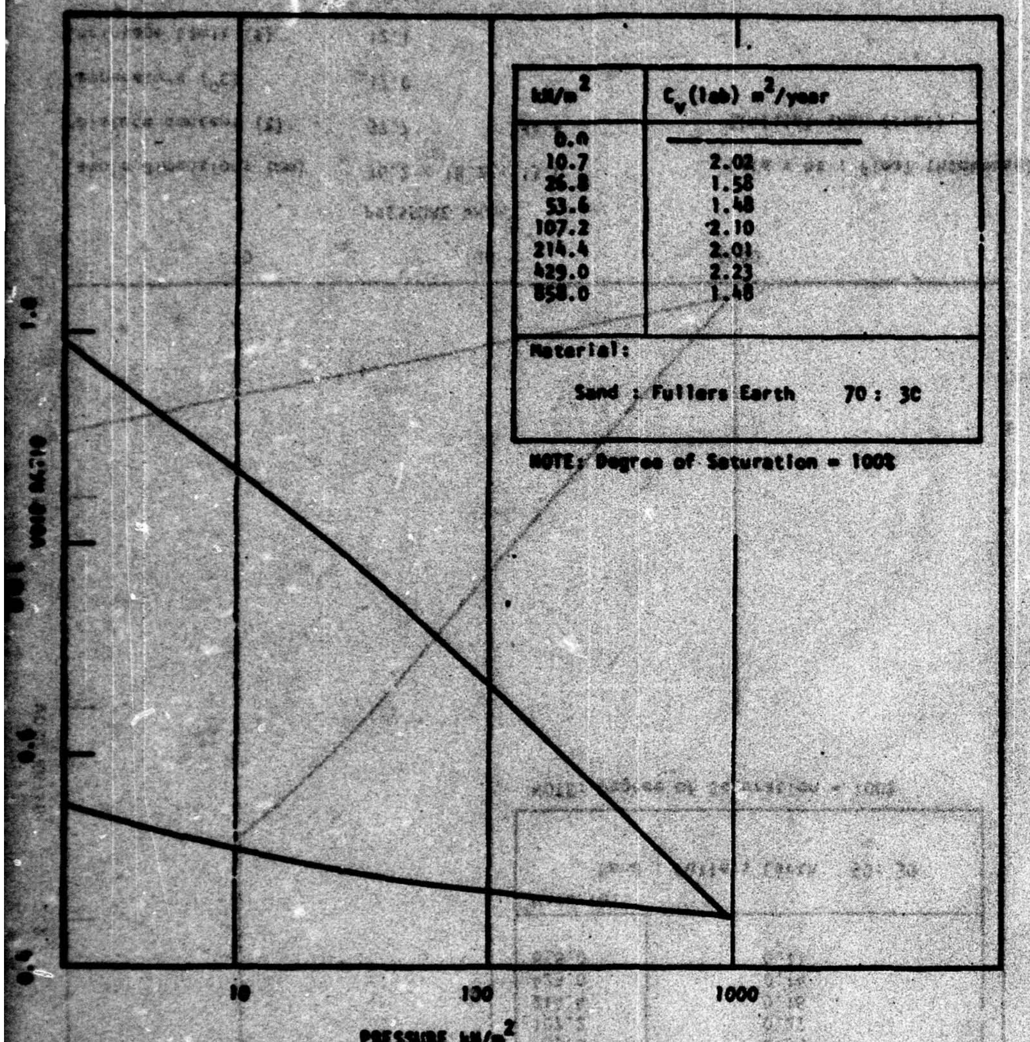
kN/m²	C_v(lab) m²/year
0.0	--
10.7	0.42
21.4	0.30
53.6	0.27
107.2	C.22
214.4	0.12
429.0	0.14
858.0	C.08

Material:

Sand : Fullers Earth 30 : 70

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	76.2 x 19.6 : 14.0		(dia x ht : final thi
Moisture content (%)	82.2	49.7	(initial then final)
Temperature (°C)	17.0		
Shrinkage Limit (%)	16.4		
Initial void ratio:	2.187		
Oc:	0.550		



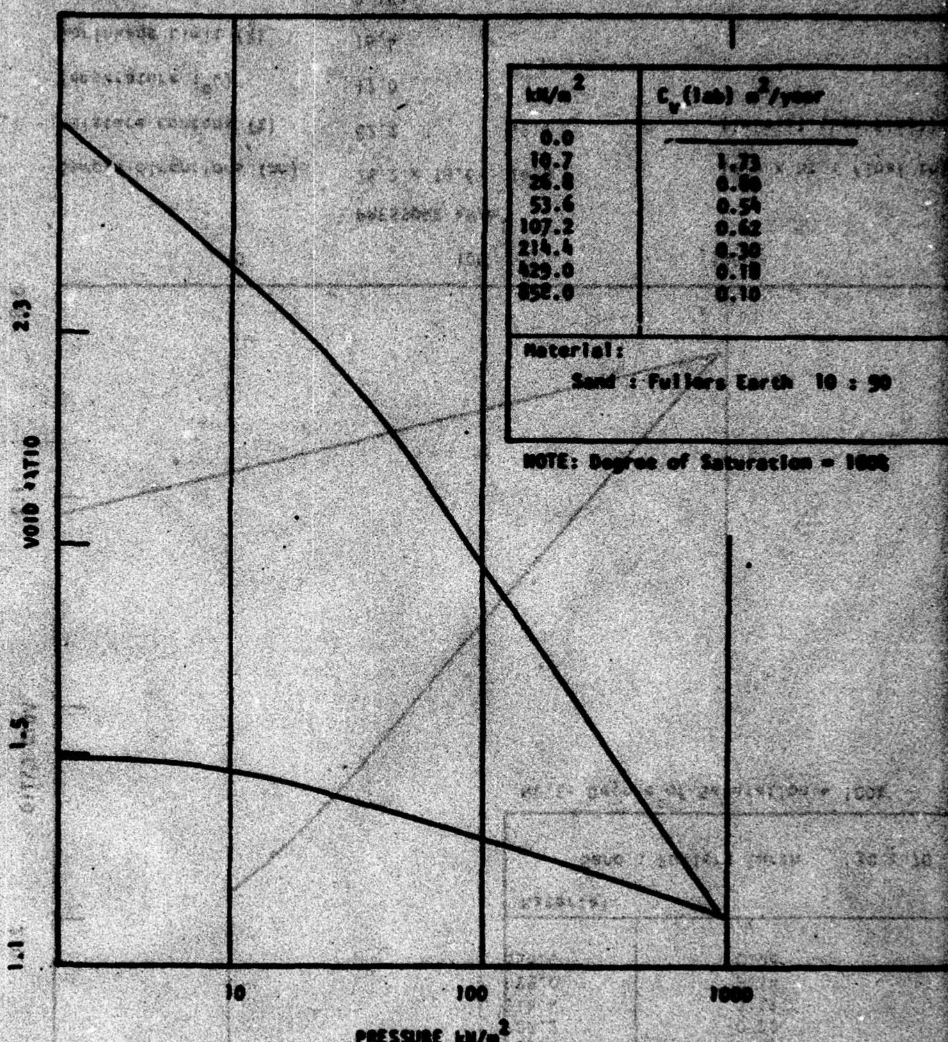
kN/m²	C_v(lab) m²/year
0.0	—
10.7	2.02
26.8	1.58
53.6	1.48
107.2	2.10
214.4	2.01
429.0	2.23
858.0	1.48

Material:

Sand : Fullers Earth 70 : 30

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	76.2 x 17.3 : 13.0		(dia x ht : final thickness)
Moisture content (%)	45.5	24.7	(initial then final)
Temperature (°C)	17.0		
Shrinkage Limit (%)	4.3		
Initial void ratio:	1.102		
Oc:	0.234		



kN/m²	C_v(lab) m²/year
0.0	—
10.7	1.73
26.8	0.86
53.6	0.54
107.2	0.62
214.4	0.30
429.0	0.18
858.0	0.10

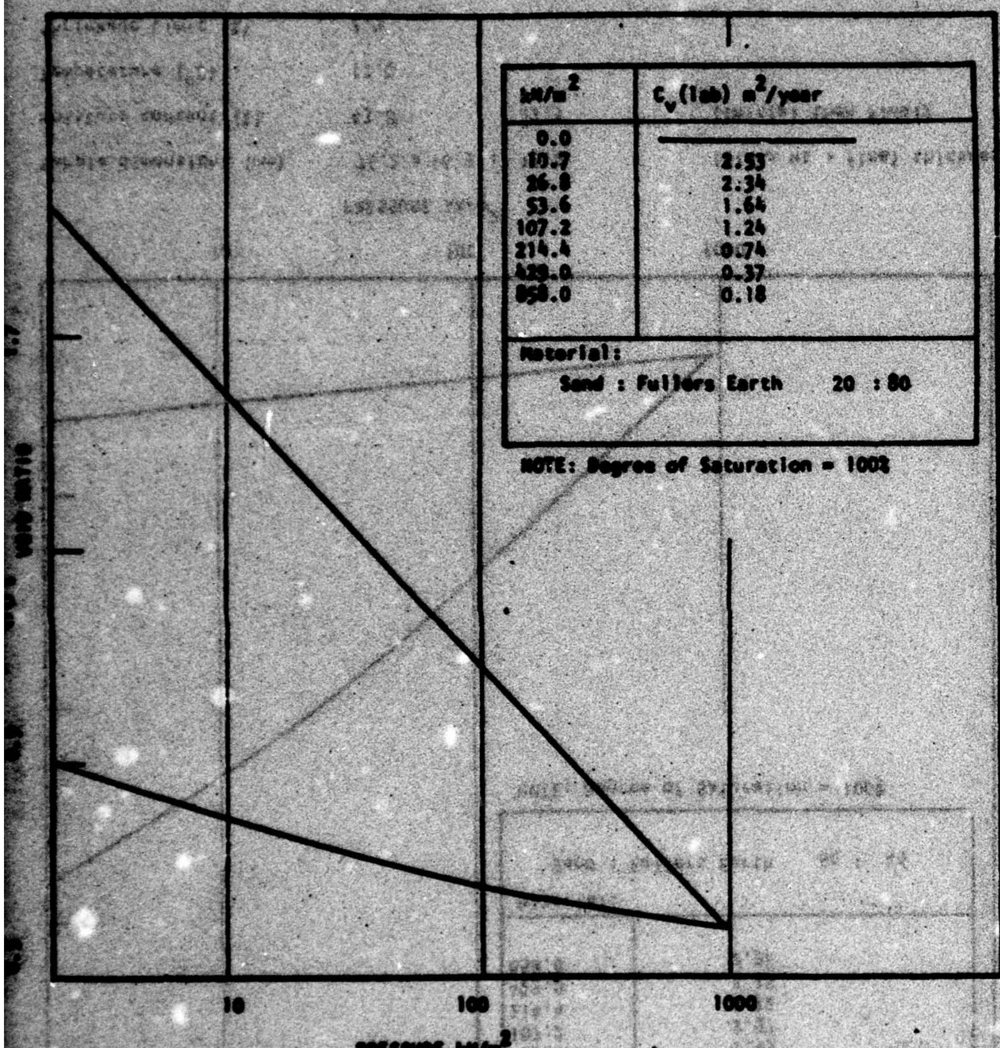
Material:

Sand : Fullers Earth 10 : 90

NOTE: Degree of Saturation = 100%

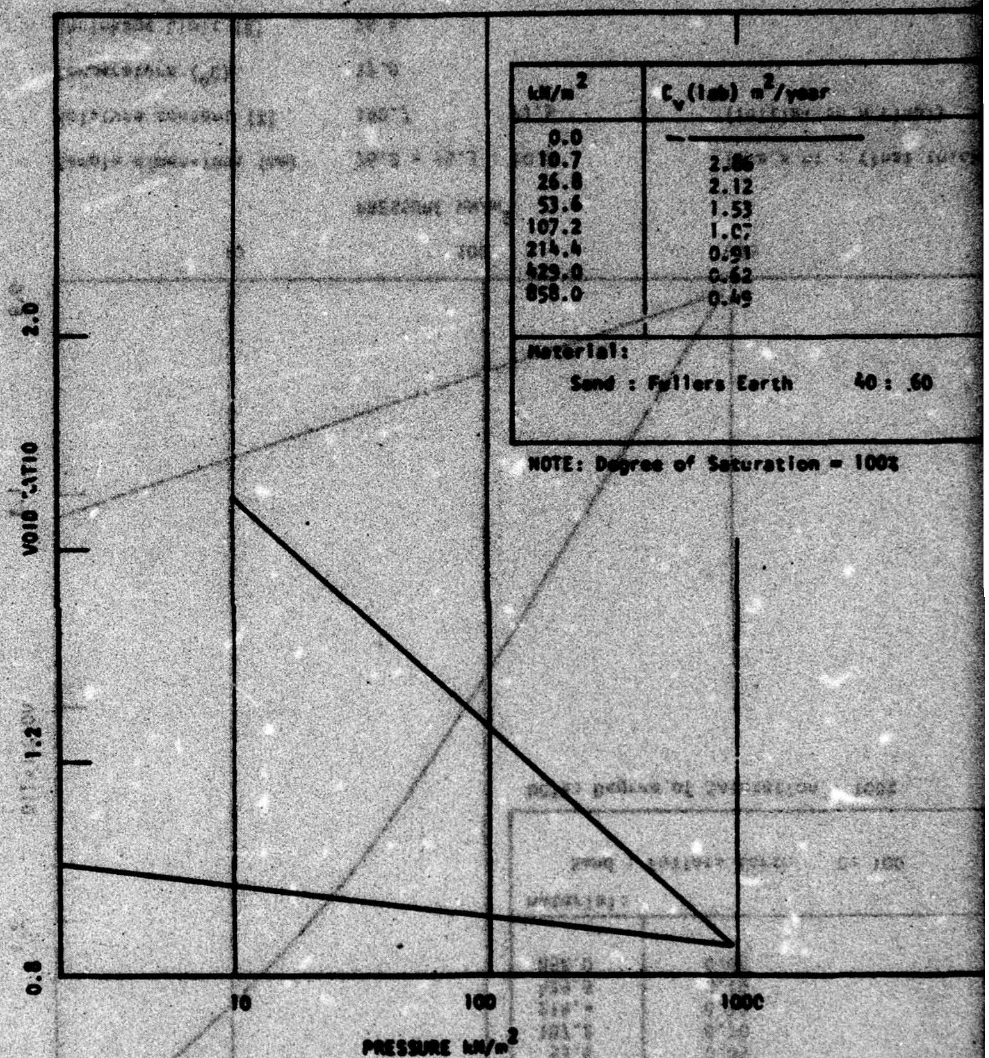
Sample dimensions (mm)	76.2 x 18.1 : 11.5		(dia x ht : final thickness)
Moisture content (%)	112.2	60.7	(initial then final)
Temperature (°C)	17.0		
Shrinkage Limit (%)	25.0		
Initial void ratio:	2.925		
Oc:	0.698		

55

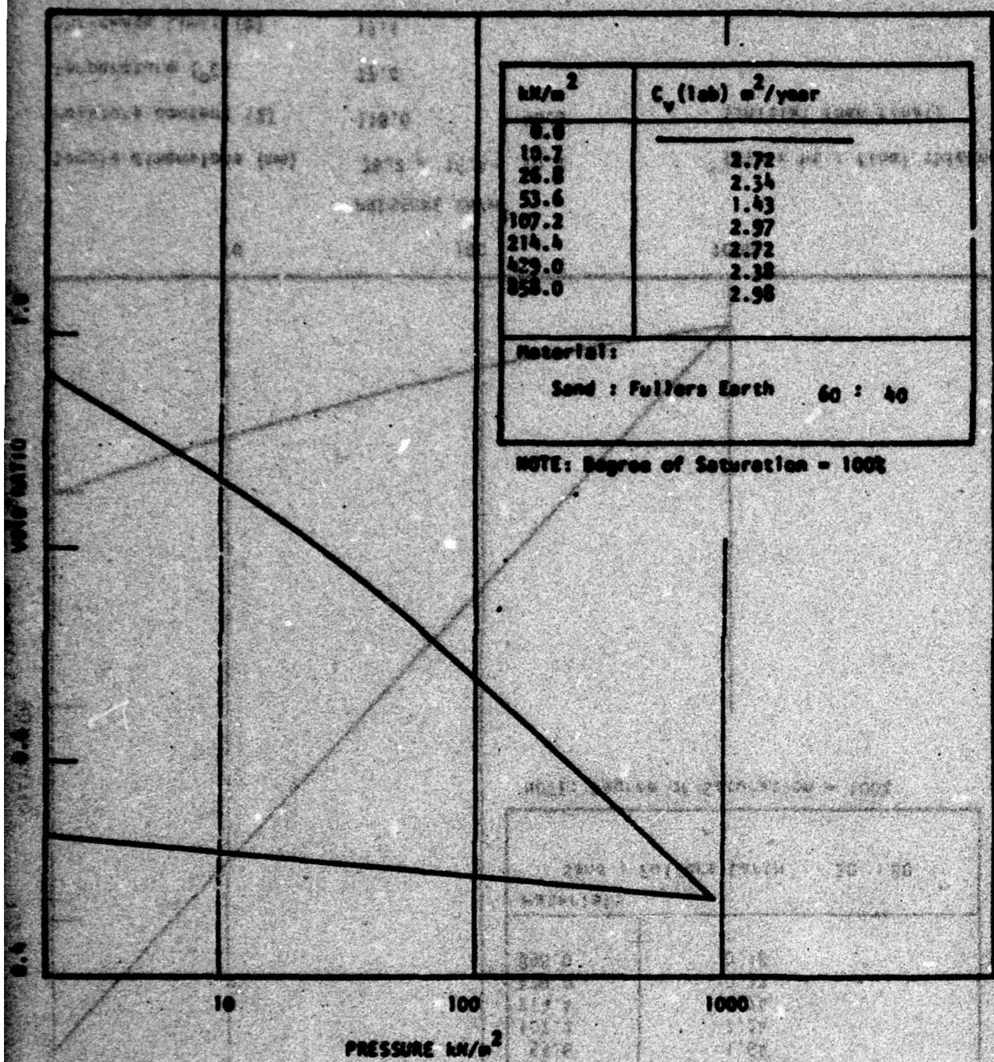


Sample dimensions (mm)	76.2 x 16.[illegible] : 10.2		(dia x ht : final thickness)
Moisture content (%)	118.0	46.5	(initial then final)
Temperature (°C)	17.0		
Shrinkage Limit (%)	17.1		
Initial void ratio:	2.180		
Oc:	0.520		

56



Sample dimensions (mm)	76.2 x 17.7 : 11.0		(dia x ht : final thic
Moisture content (%)	79.9	51.8	(initial then final)
Temperature (°C)	17.0		
Shrinkage Limit (%)	7.9		
Initial void ratio:	2.269		
Oc:	0.453		



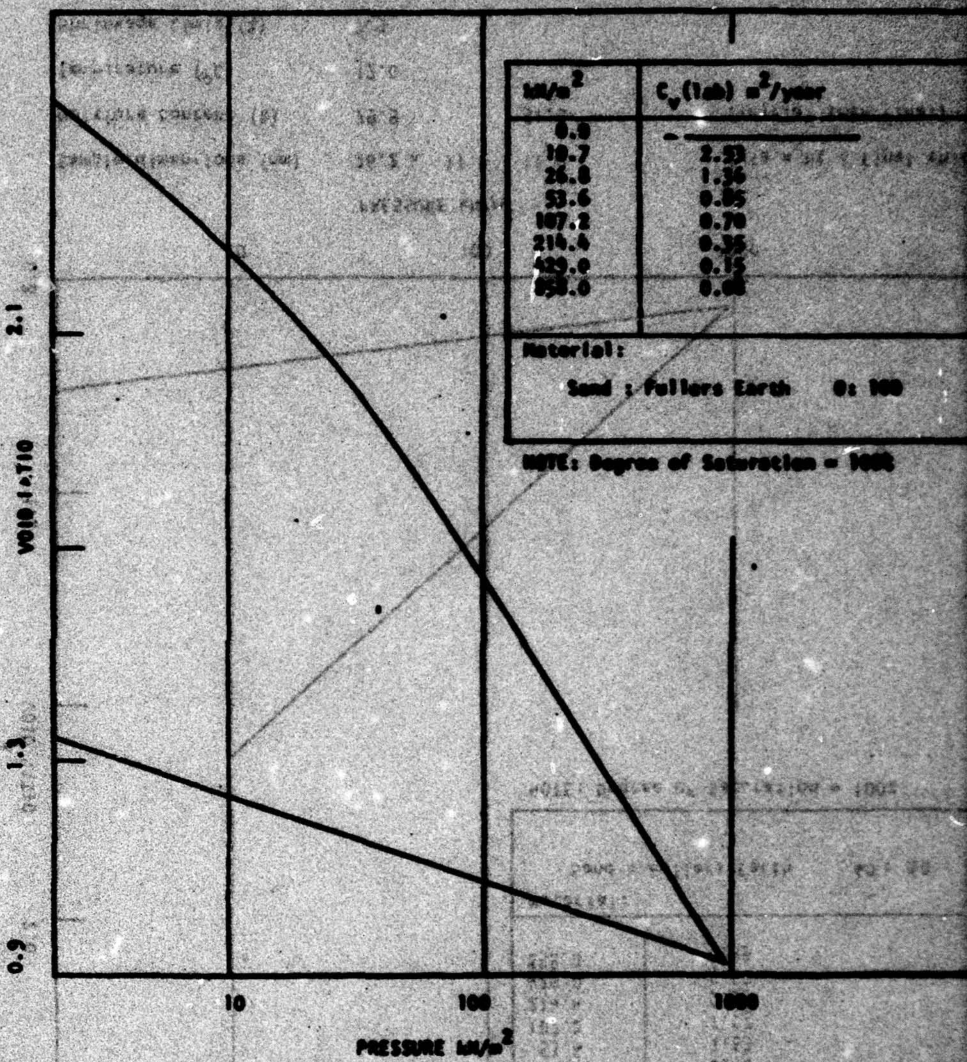
kN/m²	C_v(lab) m²/year
6.0	—
10.7	2.72
26.8	2.34
53.6	1.43
107.2	2.97
214.4	2.72
429.0	2.38
858.0	2.98

Material:

Sand : Fullers Earth 60 : 40

NOTE: Degree of Saturation = 100%

Sample dimensions (mm)	76.2 x 16.9 :	13.0	(dia x ht : final thickness)
Moisture content (%)	43.8	23.3	(initial then final)
Temperature (°C)	17.0		
Shrinkage Limit (%)	2.9		
Initial void ratio:	1.008		
Cc:	0.215		



kN/m²	C_v(lab) m²/year
6.0	—
10.7	2.53
26.8	1.36
53.6	0.85
107.2	0.70
214.4	0.35
429.0	0.15
858.0	0.08

Material:

Sand : Fullers Earth 0 : 100

NOTE: Degree of Saturation = 100%

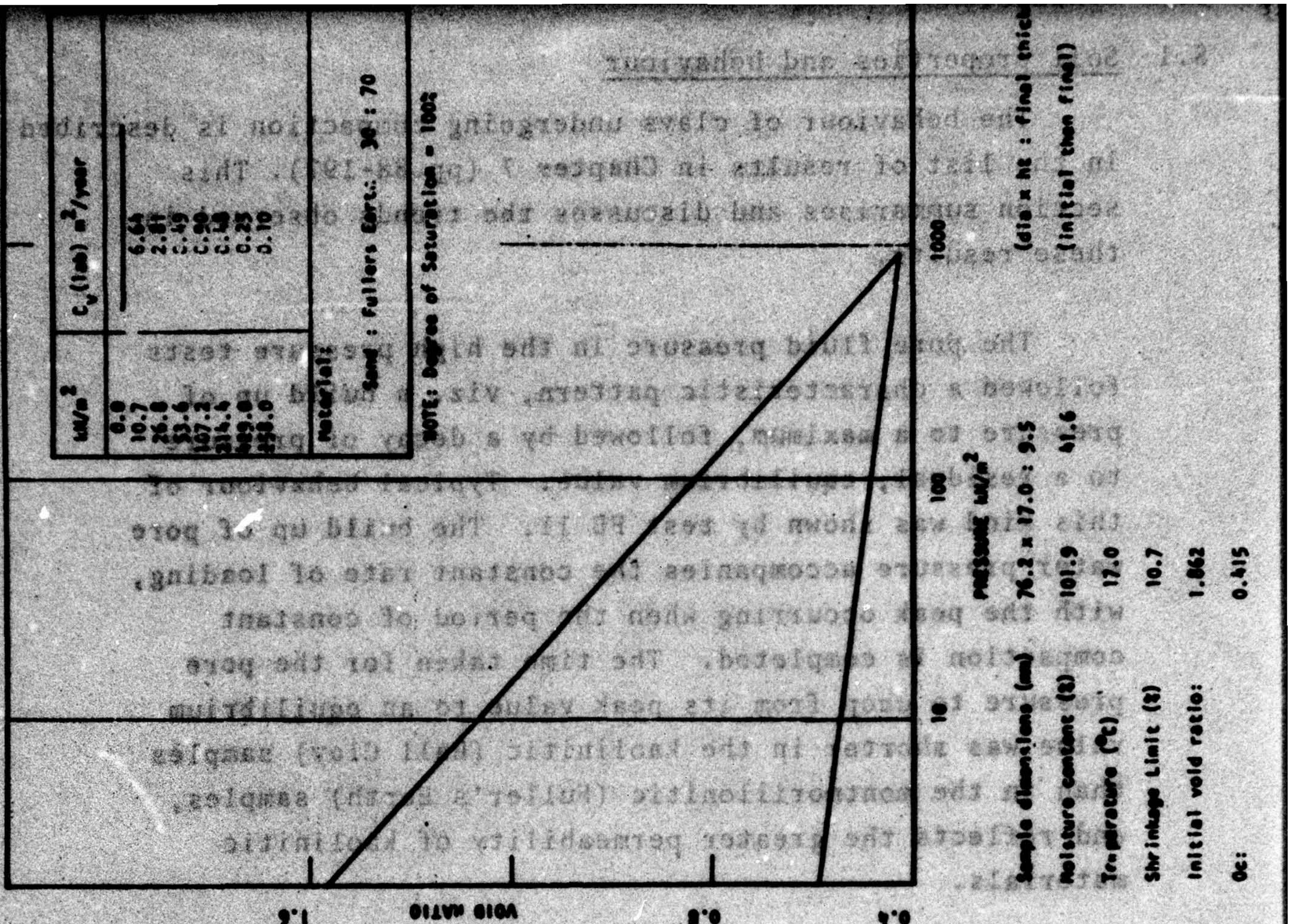
Sample dimensions (mm)	76.2 x 15.3 :	10.0	(dia x ht : final thickness)
Moisture content (%)	140.7	71.5	(initial then final)
Temperature (°C)	17.0		
Shrinkage Limit (%)	26.4		
Initial void ratio:	2.664		
Cc:	0.770		

8.1 Soil properties and behaviour

The behaviour of clays undergoing compaction is described in the list of results in Chapter 7 (pp 84-197). This section summarizes and discusses the results obtained from these results.

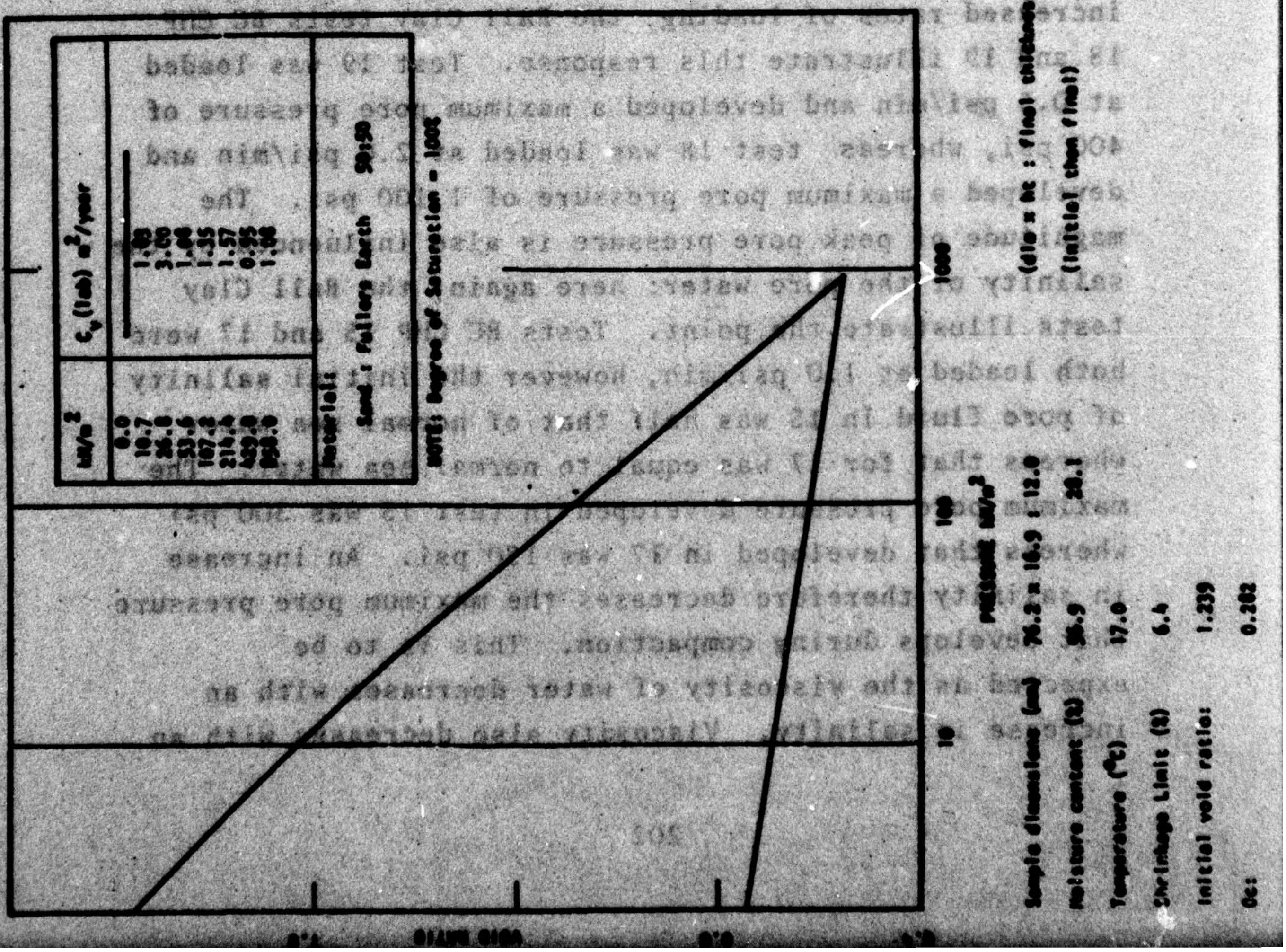
The pore fluid pressure in the high pressure tests followed a characteristic pattern, viz a build up of pressure to a maximum, followed by a decay of pressure to a residual, equilibrium value. Typical behaviour of this kind was shown by test FE 11. The build up of pore pressure accompanies the constant rate of loading, with the peak occurring when the period of constant compaction is completed. The time taken for the pore pressure to decay from its peak value to an equilibrium value was shorter in the kaolinitic (Ball Clay) samples than in the montmorillonitic (Fuller's Earth) samples, and reflects the greater permeability of kaolinitic materials.

S10



The magnitude of peak pore pressure increases with increased rates of loading. The Ball Clay tests BC 18 and 19 illustrate this response. Test 19 was loaded at 0.[illegible] psi/min and developed a maximum pore pressure of 400 psi, whereas test 18 was loaded at [illegible] psi/min and developed a maximum pore pressure of [illegible] psi. The magnitude of peak pore pressure is also influenced by the salinity of the pore water: here again the Ball Clay tests illustrate the point. Tests BC 15 and 17 were both loaded at [illegible] psi/min, however the initial salinity of pore fluid in 15 was half that of normal sea water whereas that for 17 was equal to normal sea water. The maximum pore pressure developed in test 15 was 300 psi whereas that developed in 17 was [illegible] psi. An increase in salinity therefore decreases the maximum pore pressure that develops during compaction. This is to be expected as the viscosity of water decreases with an increase in salinity. Viscosity also decreases with an

S9



8. CONCLUSIONS

8.1 Soil properties and behaviour

The behaviour of clays undergoing compaction is described in the list of results in Chapter 7 (pp.88-197). This section summarises and discusses the trends observed in these results.

The pore fluid pressure in the high pressure tests followed a characteristic pattern, viz. a build up of pressure to a maximum, followed by a decay of pressure to a residual, equilibrium value. Typical behaviour of this kind was shown by test FE 11. The build up of pore water pressure accompanies the constant rate of loading, with the peak occurring when the period of constant compaction is completed. The time taken for the pore pressure to drop from its peak value to an equilibrium value was shorter in the kaolinitic (Ball Clay) samples than in the montmorillonitic (Fuller's Earth) samples, and reflects the greater permeability of kaolinitic materials.

The magnitude of peak pore pressure increases with increased rates of loading; the Ball Clay tests BC CHP 18 and 19 illustrate this response. Test 19 was loaded at 0.5 psi/min and developed a maximum pore pressure of 400 psi, whereas test 18 was loaded at 2.0 psi/min and developed a maximum pore pressure of 1,100 psi. The magnitude of peak pore pressure is also influenced by the salinity of the pore water: here again, the Ball Clay tests illustrate the point. Tests BC CHP 15 and 17 were both loaded at 1.0 psi/min, however the initial salinity of pore fluid in 15 was half that of normal sea water whereas that for 17 was equal to normal sea water. The maximum pore pressure developed in test 15 was 300 psi whereas that developed in 17 was 150 psi. An increase in salinity therefore decreases the maximum pore pressure that develops during compaction. This is to be expected as the viscosity of water decreases with an increase in salinity. Viscosity also decreases with an

increase in temperature, and pore pressure peaks become progressively smaller as the temperature of the compacting environment increases. The Fuller's Earth tests FE 7 and FE 13 illustrate this: both samples had an initial pore fluid composed of distilled water; both were subjected to maximum consolidation pressures of 5000 psi yet test 7 was run at 40^{o}C and attained a maximum pore pressure of 1,410 psi, whereas test 13 was run at 80^{o}C and the maximum pore pressure did not exceed 700 psi.

The observations suggest that the peak pore fluid pressure is a result of the rate of pore pressure dissipation being slower than the rate of axial loading. During the early stages of consolidation specimen thickness decreases rapidly, and produces a large build up of pore pressure. Later, as the specimen thickness decreases less rapidly, the pore pressure decreases until equilibrium is attained between the rate of pore fluid expulsion and rate of loading.

The effect of effective pressure on void ratio was determined for all the compaction tests. Lower void ratios correspond to more compact materials and the results show that slower rates of compaction, higher initial pore fluid salinities and higher temperatures in the high pressure tests lead to more compact specimens

The addition of non-clay material does not change these basic trends, but does diminish the response that is developed in pure clay materials. Mixtures of Fuller's Earth and Sand (S-series) and Fuller's Earth and Chalk (a limestone) (CF-series) were tested. In both cases the increased permeability resulting from the presence of non-clay size particlesled to an increase in the coefficient of consolidation; the pure clay samples having the lowest coefficient of all.

The relationship between porosity and permeability has been evaluated for each of the high pressure tests

and reveals that kaolinitic materials respond differently in this respect from montmorillonite materials. In the Ball Clays the porosity-permeability relationship tends to be non-linear, there being a rapid decline in permeability at low porosities: see for example test BC CHP 14. This compares with a similar decrease in permeability observed in the field by Magara (1973). Such a change in the porosity permeability relationship may be a clear indication that the drainage system within the material deteriorates in some way, e.g. becomes discontinuous, at low porosities. No such change in the relationship between porosity and permeability has been observed in the tests on montmorillonite material: see for example test FE 13 although it cannot be concluded that such a change would not occur at higher pressures, or after greater de-watering. However it is fairly clear that if this change occurs in montmorillonite, it develops after a greater degree of consolidation than is necessary in kaolinites. A further understanding of this behaviour naturally leads to a consideration of fabric and fabric stability under load.

The importance of fabric cannot be over-emphasised. Three basic forms of sample preparation have been used in this work and each revealed a different response to compaction. The crudest sample preparation is represented by tests such as FE 1A: these were mixed in the specimen chamber and then consolidated. A more refined approach is represented by the test runs using Ball Clay, e.g. BC CHP 14: specimens were mixed, but were 2 inches longer than required by the high pressure apparatus so that they could be gently pre-consolidated before being subjected to a full consolidation. By far the best approach is represented by the majority of the Fuller's Earth tests, e.g. FE 13. Here slurry was sedimented directly into the cell and the compaction curves for tests FE 1A, BC CHP 14 and FE 13 reflect the differences this initial fabric has upon the consolidation of a material. The sedimented

material undergoes much more rapid compaction and exhibits less rebound during unloading.

Electron micrographs and X-ray diffraction traces show that the fabric of Ball Clay that has undergone compaction in the high pressure oedometer is greatly influenced by dewatering. In any specimen the dominant preferred orientation occurred at the drained end where the pore fluid pressure was lowest. Fig. 8.1a & b illustrates the fabrics that can develop at the drained and undrained end of specimen BC CHP 12. As can be seen the presence of coarse particles hinders the development of preferred orientation. This corresponds to the greater fissility of shales with a higher clay content. The rate of loading also affects the fabric that is developed, the slower the rate, the more oriented the fabric.

All the evidence points towards the importance of the initial fabric to consolidation behaviour. The scanning electron microphotographs reveal a close relationship between drainage and fabric, and the compaction records underline the greater efficiency of naturally sedimented samples at permitting easy drainage. Compaction enhances the fundamental fabric developed during sedimentation and this enhancement commences early in the compaction process.

8.2 Pore fluid properties and behaviour

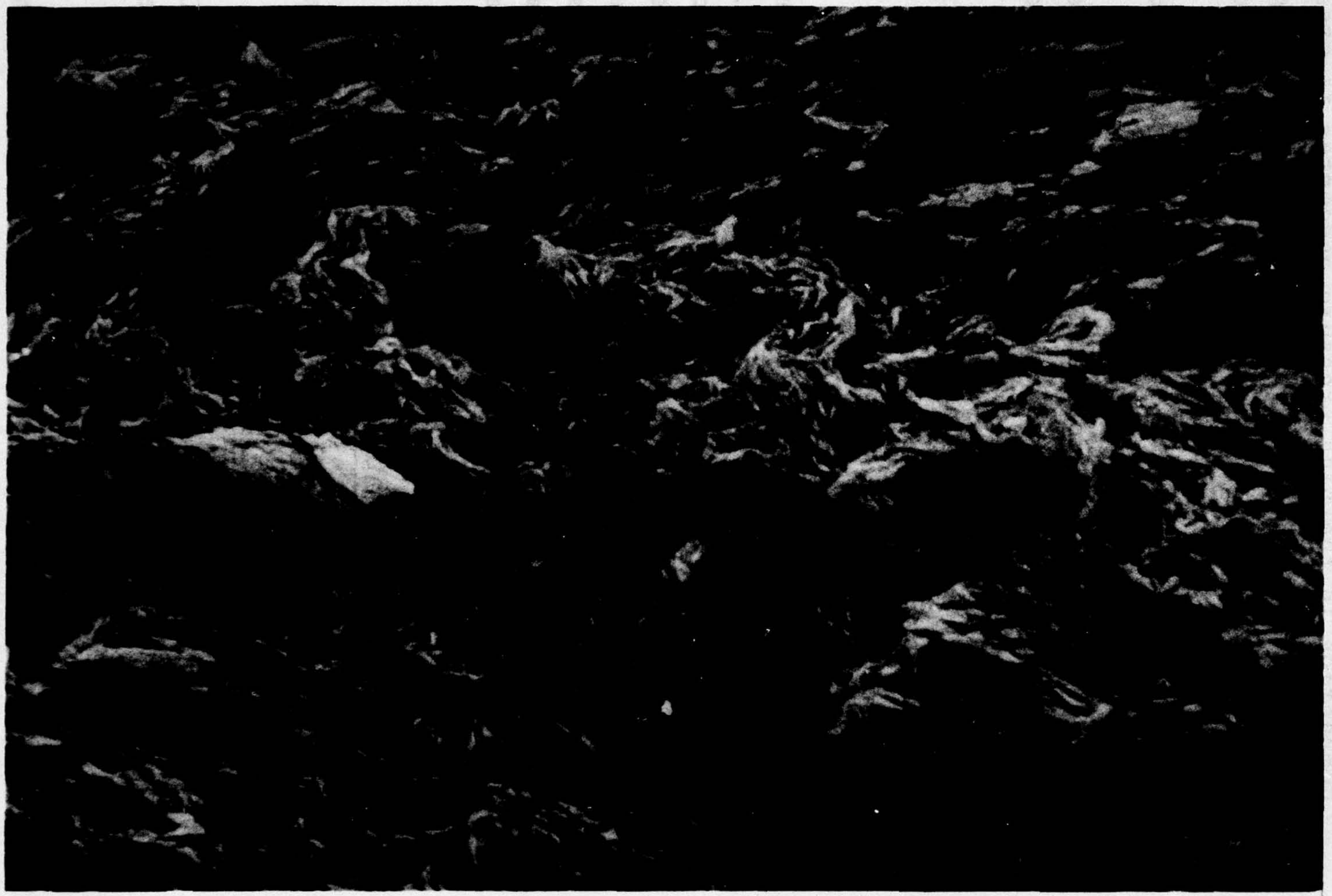
The chemical analyses of the pore fluids expelled during compaction are tabulated in Chapter 7.

For the pore fluids expelled from the Ball Clay and Fuller's Earth two prominent and separate trends have been observed.

Trend 1. The concentration of the majority of the ions decreases with increasing pressure, an important exception being the sulphates. This trend is well illustrated by tests FE 16 and 17: both were run at

Plate 8.1a. Sample from undrained end of BC CHP 12

10 μ



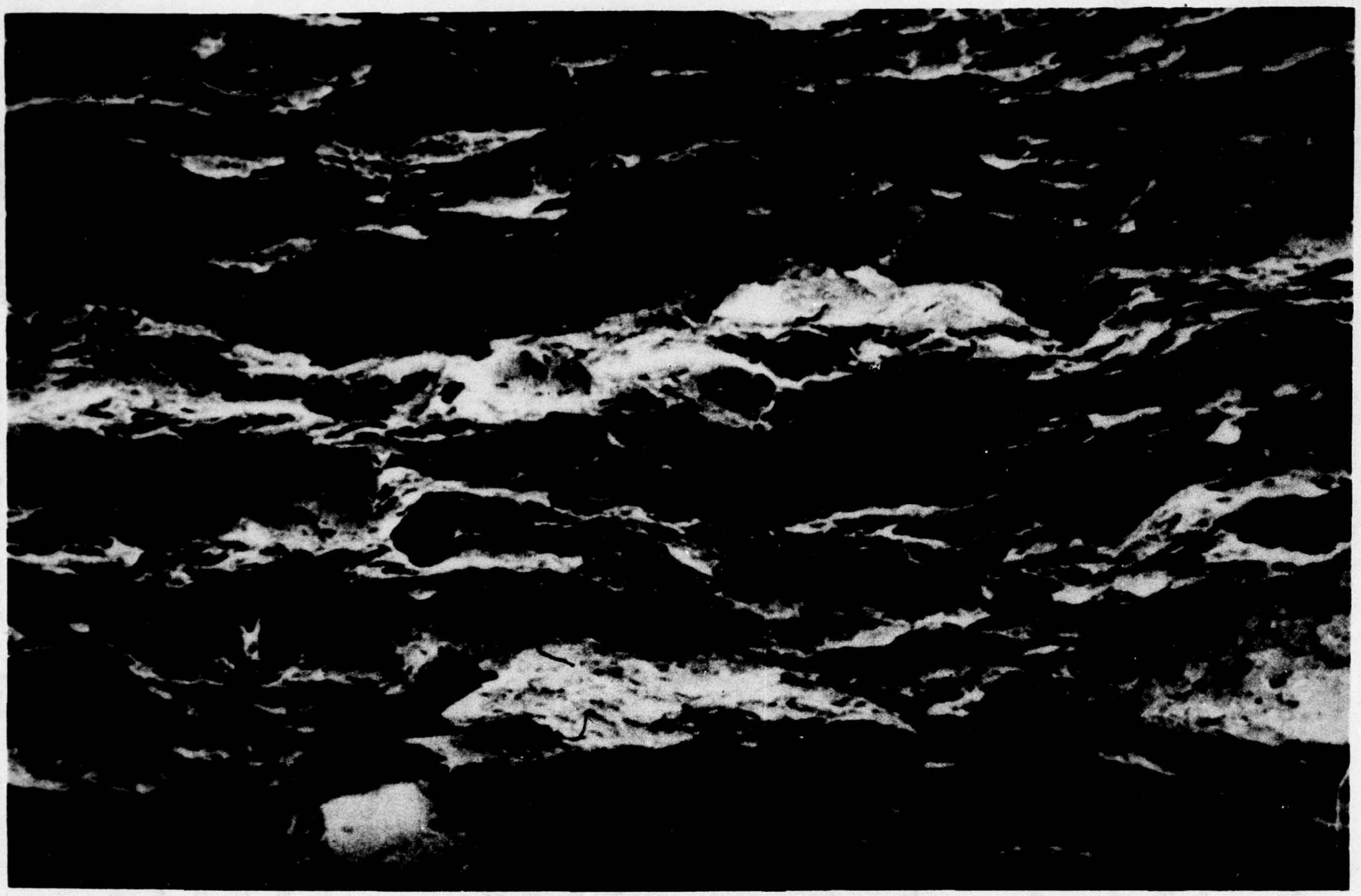


Plate 8.1b. Sample from drained end of BC CHP 12

10 μ

40°C, FE 16 having an initial pore fluid equivalent to sea water, whereas that for FE 17 was distilled water. If the initial concentration of ions is low then the amount by which the concentration decreases is very small. Chlorine and magnesium typically react in this way.

Trend 2. The concentration of ions expelled in the pore water increases with an increase in the rate of loading. The ball clay tests illustrate this: BC CHP 18 and 19. Both had distilled water as their initial pore fluid, but test 18 was run at 2 psi/hr whereas test 19 was run at 0.5 psi/hr. Potassium and sodium illustrate this trend quite clearly.

Trend 1 may well be reflecting pore fluid filtration either by a physical filtration of large ions by a small porous network, or by the chemical filtration of base exchange attracting ions to the clay minerals, or by a combination of both processes.

Trend 2 suggests that an energy balance can be studied for compacting sediments; i.e. the energy is equal to that entering the system plus any energy either released or taken into storage within the system. The latter could be of considerable interest, and chemistry may be the most rapid way of studying this problem.

As noted in section 8.1, increases in the temperature of the pore water affect compaction behaviour. Fuller's earth tests FE 1A, 7, 11, 12, 13 and 22 were all conducted at the same rate of loading but at different temperatures. In general the higher the temperature the more rapid the decrease in ionic concentration.

Two basic processes seem to be in operation: a release system and a transport system. The release

system works more quickly when temperatures are elevated because ions around the lattices become excited and are more easily dislodged from their former position into the stream of discharging pore fluid. The transport system quickens with increasing salinity as the water molecules concentrate around the ions present in solution so breaking up the more chain-like molecular structure of purer water.

These two processes are probably exerting an influence on the way pore fluid chemistry responds to pressure. For all the Fuller's Earth tests the concentration of ions rapidly decreases with increasing stress until a level of stress is reached at which the rate of decrease markedly declines. The decrease in concentration is exponential but shows a break in curvature indicating two distinct phases of pore fluid expulsion. This break coincides with a change in the rate of compaction. The initially rapid decrease in thickness is reduced to a slower phase which corresponds to a decrease in the volume of fluid expelled. The slower rate of expulsion enables the pore fluid to attain a greater equilibrium with the clay and thus affect its composition. The work of Rieke et al (1964) and Chilingarian et al (1973) supports the observations that the compaction of montmorillonite produces a decrease in the concentration of ions in the expelled solutions (Rosenbaum, 1976). These results imply that the mechanisms responsible for releasing ions into the pore fluid and allowing their expulsion are closely related to the mechanical compaction and dewatering of the sample.

8.3 Geological implications

Compaction tests have been carried out on clays up to a maximum stress of about 8000 psi and temperatures up to 80°C corresponding to a depth of burial of 8000 ft. of overburden. These tests have not attempted to simulate

the full effects of progressive burial and exhumation which would have required control of the pore fluid pressure and specimen temperature to simulate hydrostatic and geothermal gradients. Instead an attempt has been made to study the behaviour of kaolinitic and montmorillonitic clays under controlled conditions of compaction in order to understand the basic behaviour of clayey sediments during compaction, i.e. during changes in effective stress, to assist the interpretation of results of simulated diagenesis, to enable a more meaningful interpretation of field data and to achieve a level of knowledge that will permit predictions to be made of ground behaviour both past (i.e. geological) and future.

One prominent observation is that the rate of loading influences compaction behaviour. The results suggest that rapid rates of loading, e.g. as with rapid sediment deposition, can cause a "state of partial compaction" with residual pore fluid pressures trapped within the clay body as occur in under-consolidated clay sequences, such as the Mississipi Delta.

Another observation is that the major part of compaction occurs during the early stages of loading which conforms to the dewatering stage described in most models of gravitational compaction. Pore fluid pressure rises to a peak and falls to a constant level when the pore fluid pressure dissipation rate is in equilibrium with the rate of pressure rise due to loading. This dependence of pore pressure on compaction could be a mechanism that contributes to the evolution of anomalously high pore pressures in the deep burial of shales. However, such pressures are often interpreted as being associated with a chemical "dewatering" of hydrated mixed layer or other clay minerals; further experimental work is required on this aspect. The change in style of pore pressure change may also be related to a change

in drainage path and the ratio of horizontal to vertical permeability as progressive gravitational compaction takes place. This ratio will approximate to unity at the initial time of deposition but will progressively increase during the burial history as fabric changes progressively develop.

The change in salinity of the pore fluid also influences compaction response with more saline environments producing more compact shales. This observation may have important implications on the factors controlling the cementation state of shales and clay-shales. It has been observed in the British Coal Measures that fresh or brackish water shales (as indicated by their included fossil content) tend to be more susceptible to slaking when in a fresh state, as well as being more deeply weathered, than marine shales in the same geological sequence. However, such original sedimentary contrasts can also be reflected in mineralogical differences.

Observations of fabric showed a greater degree of preferred orientation of clay particles at the drained end of the specimen. Thus in a shale-sand sequence the shale nearer the sand body would be expected to exhibit a more compact fabric due to the higher permeability of the sand, a lower "local permeability", and increased efficiency as a semi-permeable membrane. However, such shale-sand sequences are not uncommonly associated with lateral facies changes so that individual sand layers may be in contact, at their extremities with one another. Similarly, the shallow water environment characteristically associated with shale-sand sequences are often associated with fossil structures, such as borings and worm tubes, which inter-connect between the sand layers. Unless the sand layers are well protected from each other by continuous clay layers there will be limited opportunity for the local low permeability zones to be formed.

Pore fluids expelled during tests exhibit changes in chemistry which support the "charged-ion net" theory of ionic filtration processes in clays rather than the theory that ions are filtered depending on their physical size.

The pressure of overburden alone is not sufficient to decrease the porosity of kaolinitic sediments below 15%. The heated experiments indicate a definite reduction in porosity with temperature suggesting that the geothermal gradient is probably an important, if not vital, agent contributing to the production of shales with high bulk density. In the low pressure oedometer tests, the viscosity of the pore fluid (which is inversely proportional to the temperature) has been shown to be the dominant controlling factor in the compaction process. In the high pressure tests the reduction of porosity may also result from clay mineral transformations. However, certain clay mineral transformations such as montmorillonite altering to illite are accompanied by the release of water which, as indicated, can be a source of anomalous pore fluid pressures and corresponding low density shales. Regional variations in the strength or compressibility of individual clay strata may, therefore, be related to original variations in crustal heat flow. This offers an interesting line of research of relating regional changes of the geotechnical characteristics of clays to the underlying structure rather than the subsequently deposited overburden load.

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KNILL, J.L., et al. Periodic Reports for Grant No. DA-ERO-124-74-G0085, as follows:-

Periodic Report for Period July 1974-December 1974
Periodic Report for Period January 1975-June 1975
Periodic Report for Period July 1975-December 1975

MAGARA, K., 1973. Compaction and fluid migration in Cretaceous shales of western Canada. Geol. Surv. Canada, Paper 72-18, 81 pp.

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WIJEYESEKERA, D.C., 1975. Artificial gravitational compaction of clays. PhD Thesis, Univ. of London, 604 pp.

9.2 Reports Produced

The following reports were produced prior to this Final Report.

KNILL, J.L., et al. Periodic Reports for Grant No. DA-ERO-124-74-G0085, as follows:-

Periodic Report for Period July 1974-December 1974
Periodic Report for Period January 1975-June 1975
Periodic Report for Period July 1975-December 1975
(The period December 1975-June 1976 is covered by the present report.)

OSMASTON, M.F., CLARKE, B.A., WIJEYESEKERA, D.C., de FREITAS, M.H. & BAKER, P., 1975. Apparatus for comprehensive experimental study of the deep burial and exhumation of sediments. (Internal report); 70 pp. (This report contains a large bibliography that was of relevance to the project in 1975.)

10. SUPPLEMENTARY REPORT

10.1 Introduction

In July 1976 Dr. Hoyt Lemons, of the European Office in London, and delegates from the U.S. Army visited College to review the research being undertaken. At that meeting it was suggested that an application be made for an extension to the period of the grant funding this work, at no extra cost: this was to assist our efforts in obtaining further funds from other sources. In September 1976 the extension requested was confirmed for a period of 6 months. This supplement reports the work undertaken in that period viz. July 1976 to December 1976 inclusive.

10.2 Results of high pressure work

Four high pressure tests were conducted during the period July-December 1976 which fell into the FE series listed in section 7.1.

The tests conducted during this period were:

FE 32, 35, 36 and 37

The material, loading cycle and change in axial pressure, pore fluid pressure, thickness, void ratio, permeability and coefficients of volume decrease are given in the accompanying figures. The results of the chemical analysis of the pore fluids expelled during compaction are given in tabular form.

10.3 Results of low pressure work

All work carried out on low pressure tests during this period were associated with substitution experiments and are described in section 10.4. The chemical results of FE 25 are included here as they became available during this period. Test FE 26, although listed in Chapter 6, was a trial test and no results are reported.

10.4 Results of consolidation tests with substitution

The low pressure work using the Rowe Cell was continued with an additional four experiments: FE 31, 33, 34, and 38. In addition to observing the compaction behaviour of montmorillonite, these tests were used to examine the effects of pore fluid substitution. The chemical analyses of the pore fluids expelled during compaction and substitution are given in tabular form and include those analyses not given in section 7.3

10.5 Results of unloading

The effects of unloading on the behaviour of clay specimens after compaction are detailed on the figures presented in section 10.2 relating to tests in the high pressure oedometer. As reported in section 7.4, unloading always produced a swelling of the specimen.

10.6 Results of small shear box tests

Small shear box tests have been carried out on the specimens produced in high pressure tests FE 16, 24, 27, 29, 30, 32, 35, 36 and 37. These were conducted in the manner described in section 7.5. The results are presented in tabular form.

10.7 Conclusions

The conclusions regarding the soil properties and behaviour, pore fluid properties and behaviour and the geological implications recorded in Chapter 8 were supported by the later tests reported in this Report. The high pressure tests which were carried out during the period July-December 1976 concluded the series on the compaction of Ca-montmorillonite at a constant rate of loading and constant temperature.

The most important result of this series of experiments was the isolation of temperature as a controlling factor in (i) the rate of physical compaction and (ii) the change in chemistry of the pore fluids. The final tests in this series (FE 35, 36 and 37) were conducted at the same rate of loading but with a temperature that was a predetermined function of the axial pressure. The behaviour of the montmorillonite was the same as during the constant temperature tests at the corresponding temperatures.

This result also confirmed the reproducibility of the specimen behaviour during testing in the high pressure oedometer. The compaction behaviour recorded during the low pressure tests carried out in the Rowe Cell was similar to the behaviour in the tests recorded in Chapter 7. The ability to carry out pore fluid substitution enabled a series of experiments to be performed which illustrated the effects of flushing out the existing clay pore fluid with new fluid of known chemical composition. This also enabled the effects of pore fluid substitution on pore fluid chemistry to be compared with the effects of simple compaction, such as those experiments carried out in the high pressure oedometer.

The results show that the effects of pore fluid substitution are rapidly reflected in the change in the chemistry of the expelled pore fluid and that the rate of change is proportional to the temperature. The rate of change and the magnitude of the reduction in pore fluid salinity by the substitution of distilled water was far greater than the effects produced by compaction alone, even at the much higher stress levels produced in the high pressure oedometer. This result confirmed that substitution was not the mechanism involved in changing the expelled pore fluid chemistry of Ca-montmorillonite during high pressure compaction. The mechanism proposed in Chapter 8 for explaining the observed changes in pore fluid chemistry has therefore not been disproved. This mechanism involved the gradual and progressive expulsion of the adsorbed water around clay particles as the particles were forced closer together during compaction with the less saline inner layers of adsorbed water producing a decrease, with time, in the salinity of the expelled pore fluid.

The results of the shear box tests indicated that the peak shear strength was controlled by the fabric of the compacted montmorillonite. High temperature tests and those continued to high compaction pressures produced compact fabrics which had a high shear strength. The residual shear strength was controlled by the adhesion between the clay particles as the shear strengths recorded were not significantly different for materials that had been compacted at different temperatures or pressures. However, the adhesion is affected by the presence of saline pore fluids and the tests carried out on montmorillonite sedimented in distilled water produced lower residual shear strength parameters than those sedimented in saline water.

TEST NO. FE 32 **Date 7.5.76**

DETAILS OF TEST MATERIAL

Fullers Earth remoulded in saline water and allowed to soak for 3 days before sedimenting direct into Cell

TYPE OF TEST

Rate of loading; 10 psi/hr

Rate of unloading; 20 psi/hr

Salinity of initial pore fluid; unit salinity

Maximum consdidation pressure; 5000 psi held for 15 days

PROPOSED INVESTIGATION

Compaction of Ca-montmorillonite at 80^{o}C

INITIAL CONDITION OF SAMPLE

Thickness; 3.108 inches

Air dry weight; 404.8 g

FINAL CONDITION OF SAMPLE

Moisture content; 27.5%

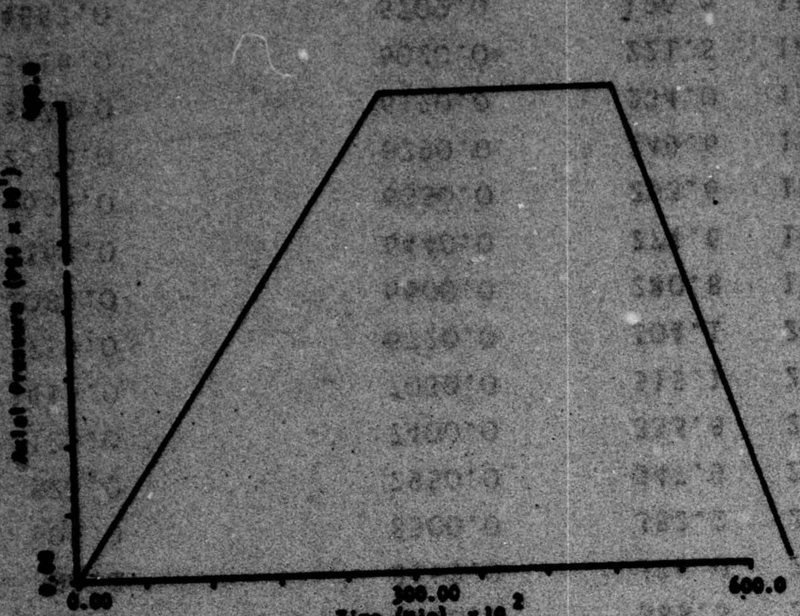
Thickness; 1.204 inches

Weight; 451.2 g

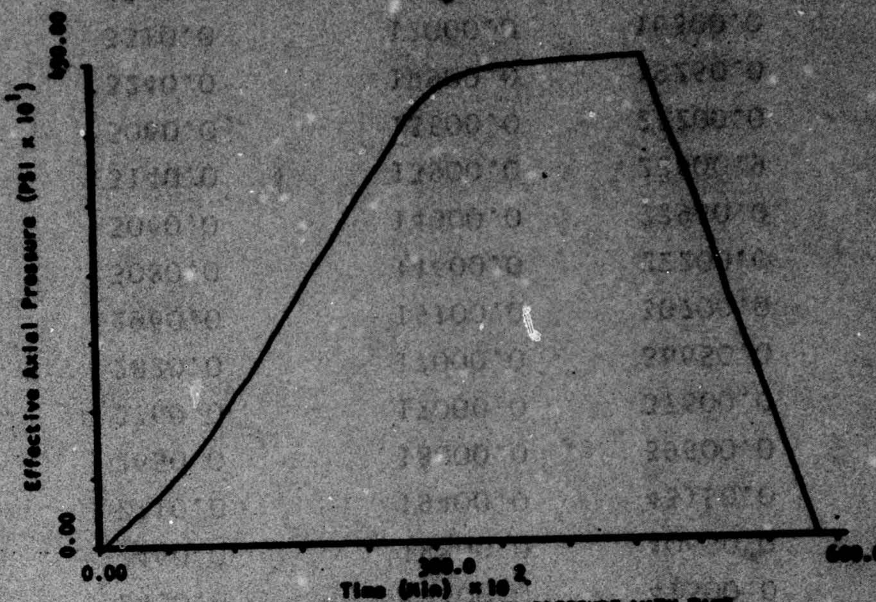
FURTHER COMMENTS

TABLE 10.1 - Results of chemical analysis of pore fluids expelled from FE 32

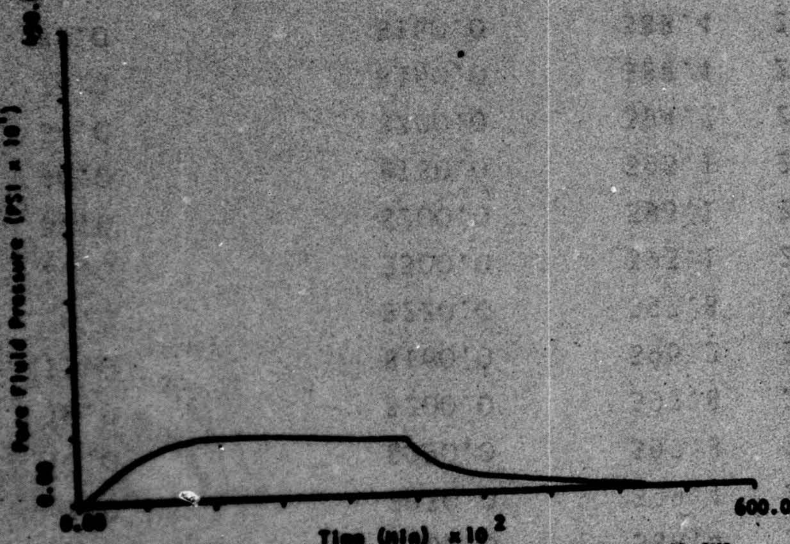
Axial Pressure MN/m^2	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
	Concentration mg/1						
2.0	5760.0	283.9	2030.0	430.6	1960.0	19100.0	41450.0
4.0	8260.0	388.4	2960.0	634.9	2010.0	18900.0	40150.0
5.0	8030.0	399.4	2930.0	686.4	2000.0	19100.0	41300.0
10.0	8090.0	397.8	2400.0	705.1	2150.0	19400.0	38900.0
10.0	8200.0	397.8	2960.0	734.8	2290.0	19400.0	40200.0
15.0	8160.0	396.2	2740.0	711.4	2310.0	19000.0	39700.0
20.0	8220.0	397.8	2740.0	744.1	2400.0	19200.0	40300.0
22.0	3300.0	393.1	2870.0	756.6	2330.0	19500.0	40250.0
32.0	8200.0	393.1	2840.0	753.5	2290.0	19500.0	40440.9
40.0	8180.0	393.1	2810.0	750.4	2280.0	19500.0	40650.0
54.0	8300.0	394.7	2730.0	750.4	2280.0	19500.0	40650.0
74.0	8160.0	388.4	2730.0	764.4	2280.0	19300.0	42100.0
88.0	8160.0	388.4	2740.0	897.0	2250.0	19300.0	41050.0
161.0	8480.0	404.0	2840.0	998.4	2440.0	20000.0	43250.0
263.0	8030.0	385.3	2670.0	917.3	2450.0	19300.0	41300.0
390.0	8160.0	376.0	2510.0	928.2	2460.0	18800.0	40650.0
605.0	8300.0	382.2	2540.0	964.1	2710.0	19400.0	43150.0
825.0	7950.0	347.9	2360.0	798.7	2650.0	18000.0	39500.0
1125.0	7400.0	333.8	2200.0	739.4	2760.0	17000.0	37600.0
1415.0	7030.0	315.1	2170.0	694.2	2820.0	17000.0	36650.0
1759.0	6720.0	301.1	2000.0	655.2	2960.0	15100.0	30700.0
2085.0	6600.0	280.8	1830.0	616.2	3080.0	14600.0	22200.0
2364.0	6440.0	274.6	1890.0	605.3	3060.0	14000.0	22950.0
2653.0	6350.0	263.6	1780.0	594.4	3140.0	13900.0	22600.9
2990.0	6290.0	249.6	1560.0	569.4	3060.0	13500.0	22200.0
3430.0	6170.0	234.0	1560.0	539.0	3240.0	19900.0	19250.0
3916.0	6020.0	221.5	1420.0	517.9	3310.0	12000.0	16300.0
4587.0	5700.0	196.6	1390.0	483.6	3360.0	11500.0	13350.0



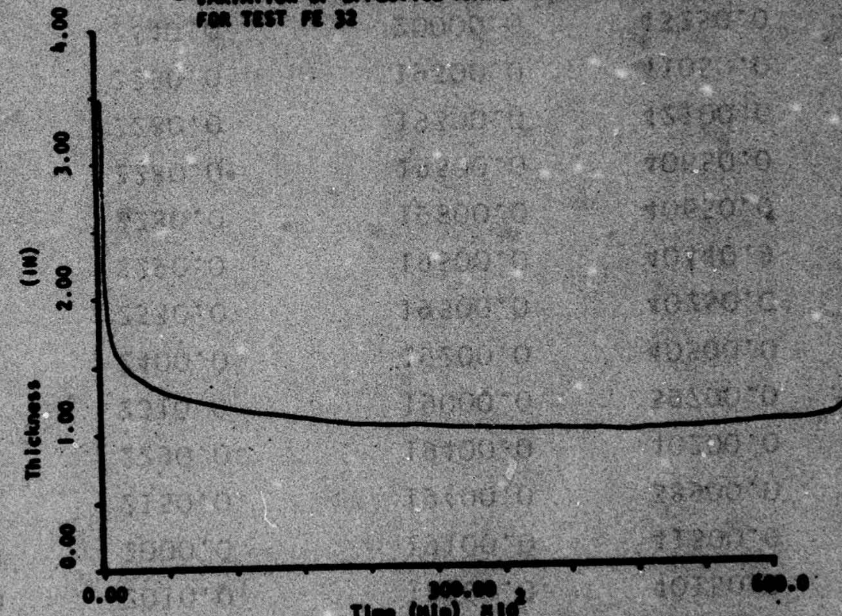
- VARIATION OF AXIAL PRESSURE WITH TIME FOR TEST FE 32



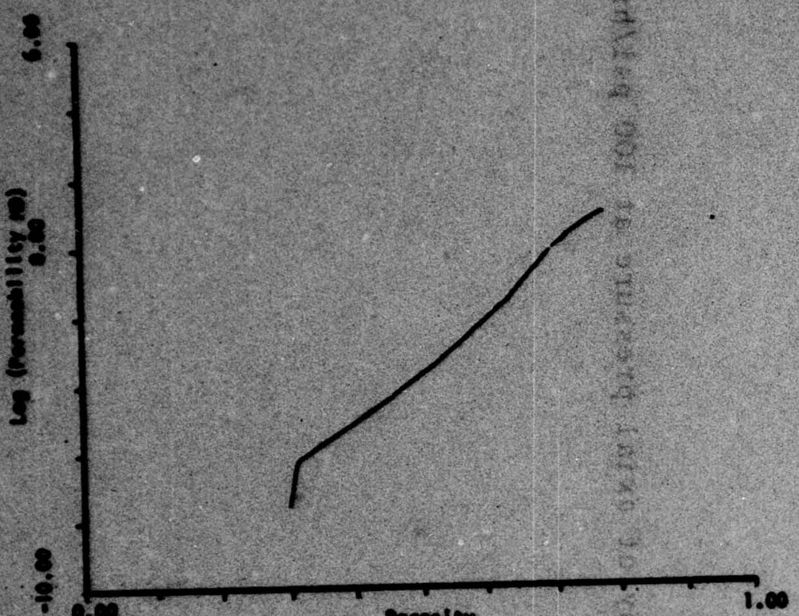
- VARIATION OF EFFECTIVE AXIAL PRESSURE WITH TIME FOR TEST FE 32



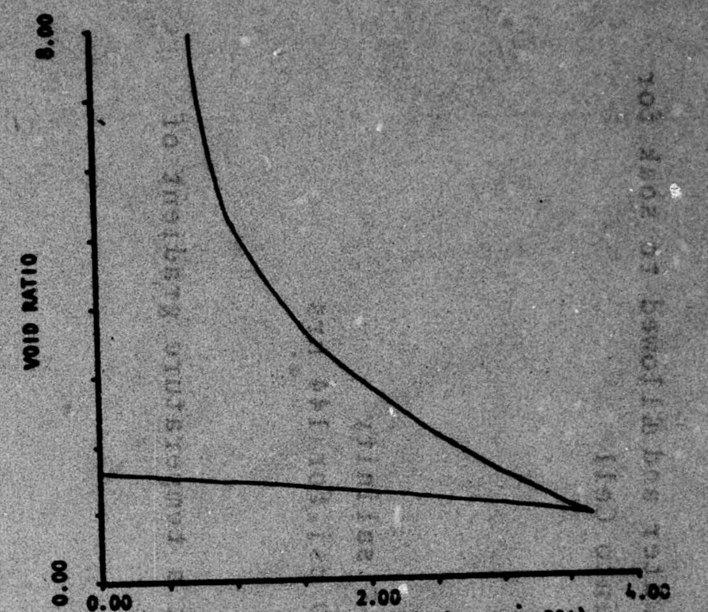
- VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME FOR TEST FE 32



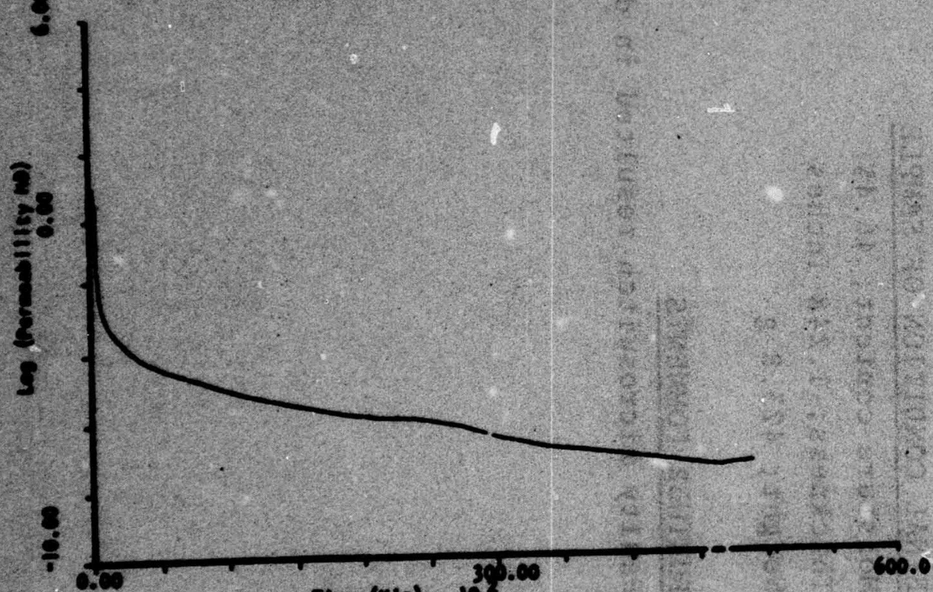
- CHANGE IN THICKNESS OF THE SAMPLE WITH TIME FOR TEST FE 32



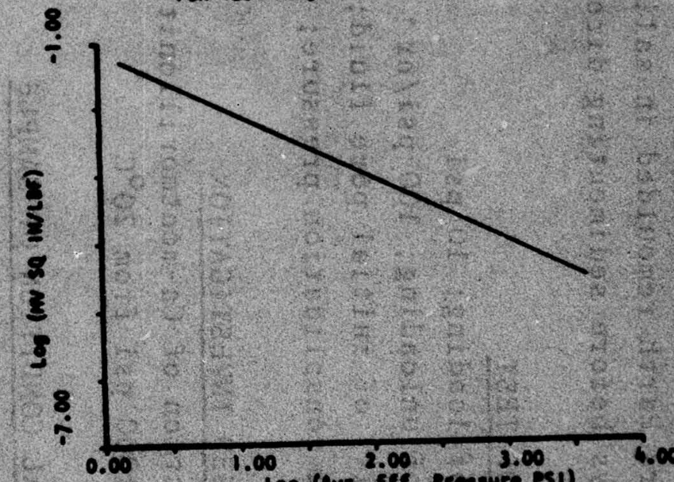
- VARIATION OF PERMEABILITY WITH POROSITY FOR TEST FE 32



VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE FOR TEST FE 32



- VARIATION OF PERMEABILITY WITH TIME FOR TEST FE32



- VARIATION OF COEFF. OF VOLUME DECAEASE WITH EFFECTIVE PRESSURE FOR TEST FE32

TEST NO. FE 35 **Date 6.7.76**

DETAILS OF TEST MATERIAL

Fullers Earth remoulded in saline water and allowed to soak for 12 days before sedimenting direct into Cell

TYPE OF TEST

Rate of loading; 10 psi

Rate of unloading; 100 psi/hr

Salinity of initial pore fluid; unit salinity

Maximum consolidation pressure; 1000 psi for 144 hrs

PROPOSED INVESTIGATION

Compaction of Ca-montmorillonite at a temperature gradient of $10^{\circ}C/1000$ psi from $20^{\circ}C$

INITIAL CONDITION OF SAMPLE

Thickness; 2.446 inches

Air dry weight; 350.8 g

FINAL CONDITION OF SAMPLE

Moisture content; 46.4%

Thickness; 1.248 inches

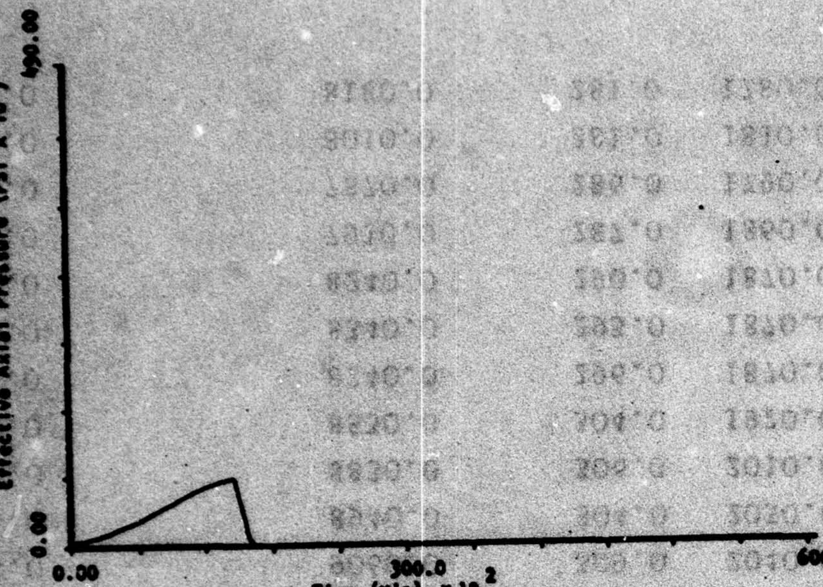
Weight; 423.8 g

FURTHER COMMENTS

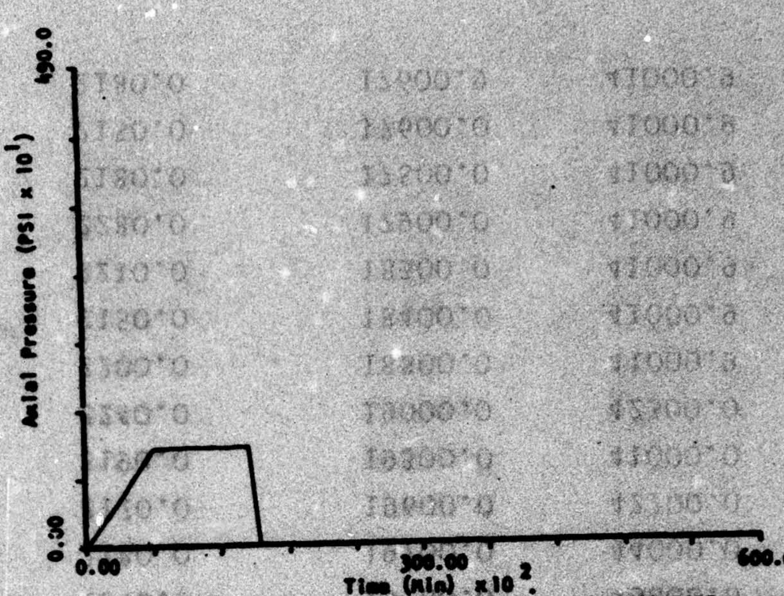
Faulty microswitch resulted in decay of axial pressure at 100 psi/hr

TABLE 10.2 - Results of chemical analysis of pore fluids expelled from FE 35

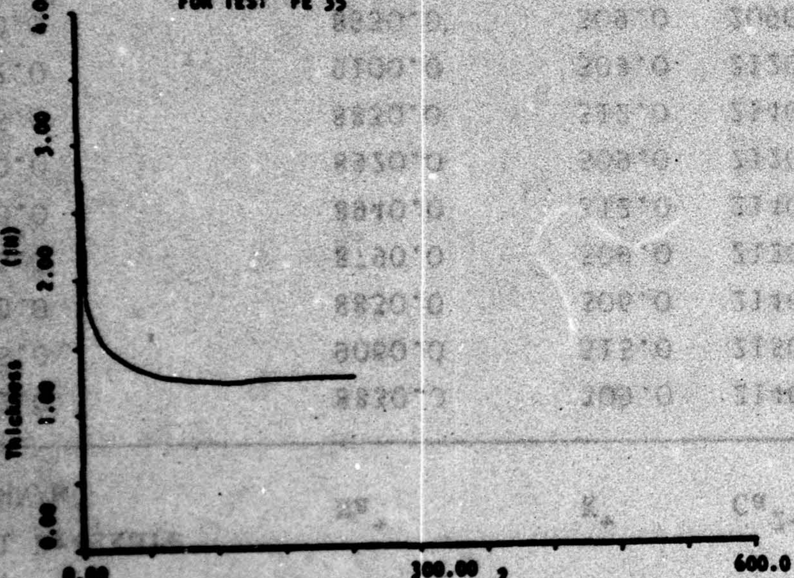
Axial Pressure MN/m^2	Concentration mg/1 Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
2.0	8830.0	309.0	2140.0	630.0	1900.0	19700.0	44000.0
5.0	9060.0	315.0	2150.0	630.0	1980.0	19600.0	44000.0
10.0	8830.0	306.0	2140.0	627.0	1910.0	19600.0	43300.0
15.0	8790.0	309.0	2120.0	633.0	1960.0	19600.0	44100.0
20.0	8940.0	312.0	2140.0	633.0	2060.0	19700.0	43900.0
30.0	8920.0	309.0	2120.0	636.0	2230.0	19600.0	44100.0
35.0	8830.0	312.0	2140.0	626.0	2190.0	19700.0	43600.0
42.0	9100.0	309.0	2120.0	643.0	3220.0	19600.0	44000.0
60.0	8830.0	309.0	2090.0	643.0	2060.0	19600.0	44200.0
78.0	9100.0	312.0	2090.0	643.0	2040.0	19700.0	43800.0
164.0	9060.0	309.0	2040.0	655.0	2180.0	19700.0	44000.0
276.0	8940.0	304.0	2030.0	655.0	2120.0	19600.0	42700.0
397.0	8830.0	306.0	2010.0	655.0	2190.0	19300.0	41000.0
542.0	8530.0	304.0	1920.0	658.0	2240.0	19000.0	42300.0
672.0	8240.0	296.0	1870.0	655.0	2200.0	18800.0	41000.9
783.0	8340.0	293.0	1870.0	655.0	2150.0	18400.0	41000.9
919.0	8240.0	290.0	1870.0	655.0	2210.0	18300.0	41000.9
1018.0	7910.0	287.0	1860.0	666.0	2280.0	17900.0	41000.9
1003.0	7870.0	286.0	1790.0	658.0	2180.0	17500.0	41000.9
990.0	8010.0	281.0	1810.0	655.0	2150.0	17600.0	41000.9
990.0	8180.0	281.0	1780.0	655.0	2180.0	17600.9	41000.9



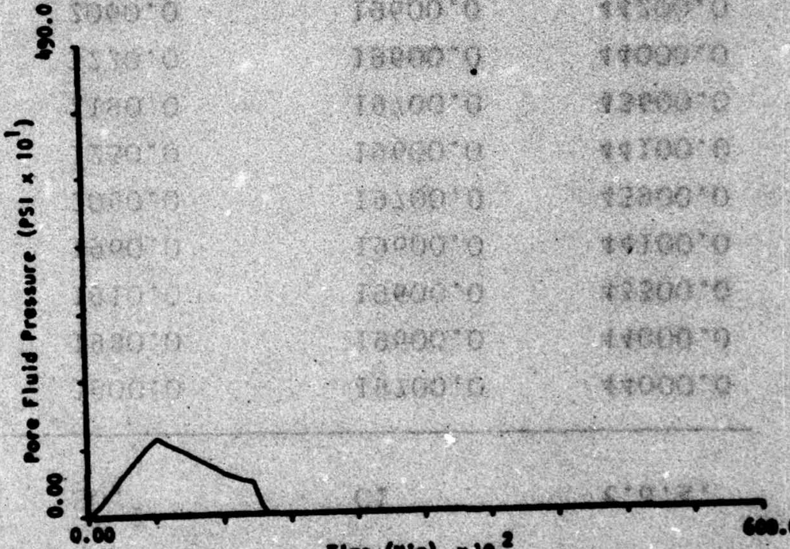
- VARIATION OF EFFECTIVE AXIAL PRESSURE WITH TIME FOR TEST FE 35



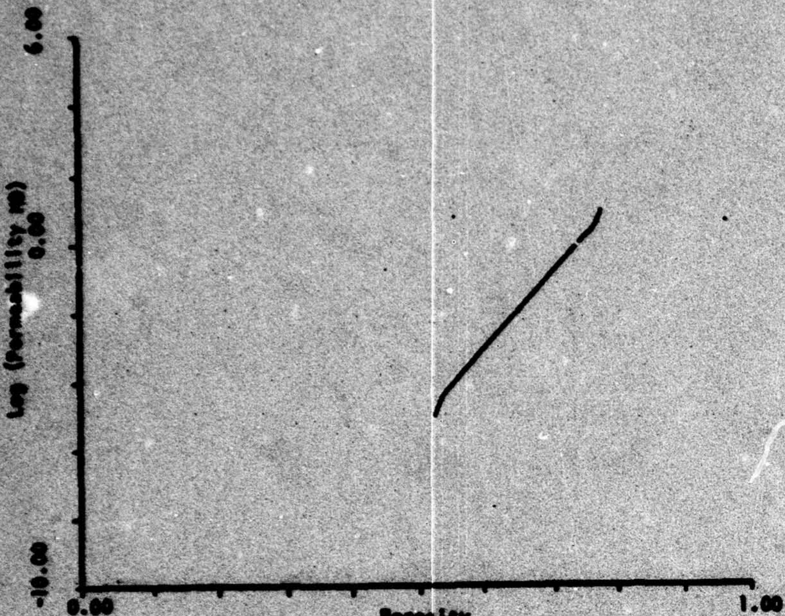
- VARIATION OF AXIAL PRESSURE WITH TIME FOR TEST FE 35



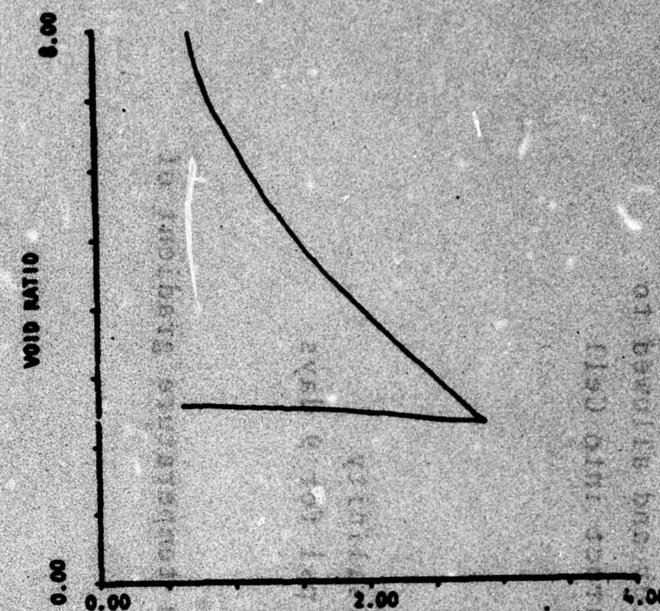
- CHANGE IN THICKNESS OF THE SAMPLE WITH TIME FOR TEST FE 35



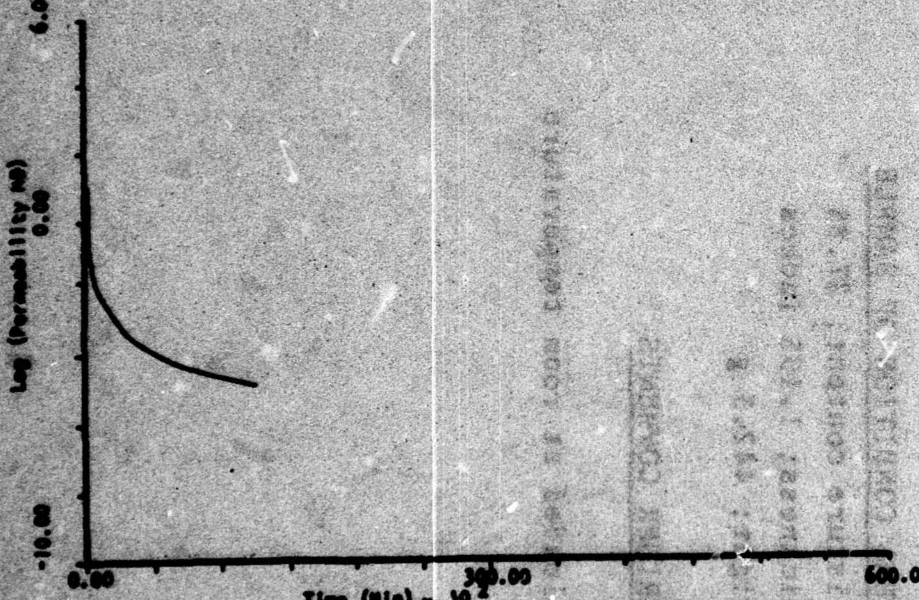
- VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME FOR TEST FE 35



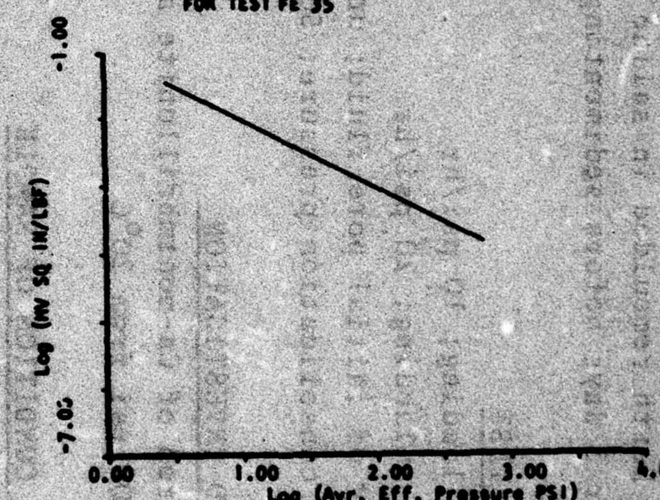
- VARIATION OF PERMEABILITY WITH POROSITY FOR TEST FE 35



VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE FOR TEST FE 35



- VARIATION OF PERMEABILITY WITH TIME FOR TEST FE 35



- VARIATION OF COEFF. OF VOLUME DECREASE WITH EFFECTIVE PRESSURE FOR TEST FE 35

TEST NO. FB 36 **Date 6.8.76**

DETAILS OF TEST MATERIAL

Fullers Earth remoulded in saline water and allowed to soak for 3 days before sedimenting direct into Cell

TYPE OF TEST

Rate of loading; 10 psi/hr

Rate of unlaoding; 20 psi/hr

Salinity of initial pore fluid; unit salinity

Maximum consolidation pressure; 5000 psi for 9 days

PROPOSED INVESTIGATION

Compaction of Ca-montmorillonite at a temperature gradient of $10^{o}C/1000$ psi from $20^{o}C$

INITIAL CONDITION OF SAMPLE

Thickness; 3.103 inches

Air dry weight; 401.1 g

FINAL CONDITION OF SAMPLE

Moisture content; 27.8%

Thickness; 1.195 inches

Weight; 442.3 g

FURTHER COMMENTS

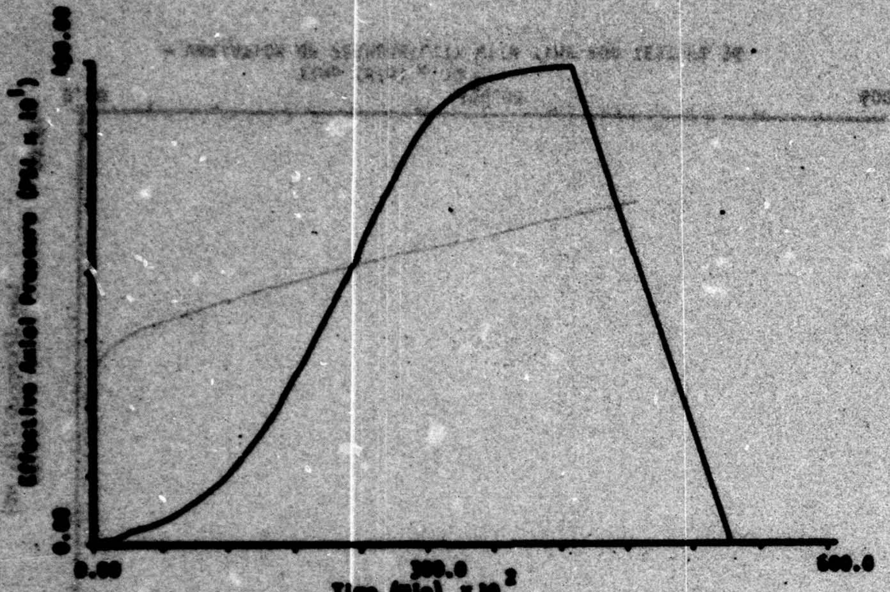
Unloaded at room temperature

TABLE 10.3 - Results of chemical analysis of pore fluids expelled from FE 36

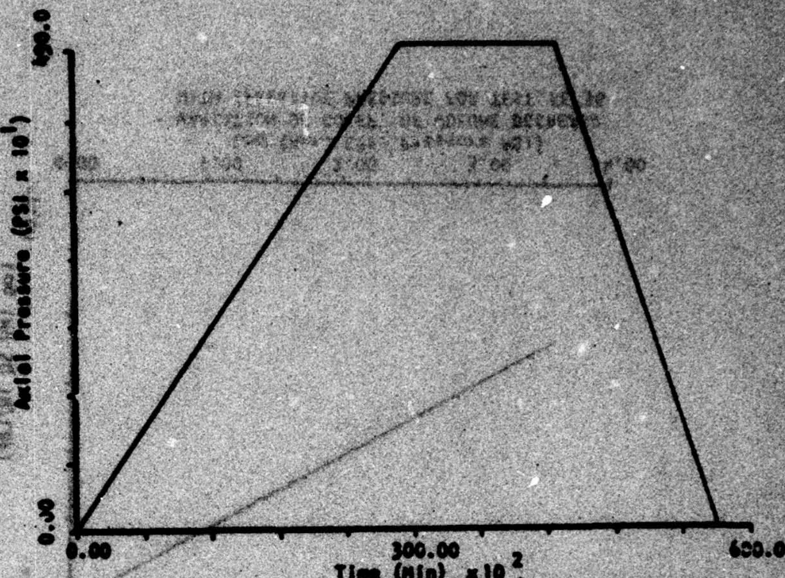
Axial Pressure MN/m^2	Concentration mg/l Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
2.0	8320.0	303.0	2430.0	927.0	2310.0	19000.0	39400.0
5.0	8360.0	314.0	2430.0	945.0	2640.0	19800.0	41000.0
5.0	8360.0	312.0	2430.0	945.0	2840.0	19500.0	40900.0
10.0	8460.0	309.0	2320.0	945.0	1910.0	19300.0	40400.0
12.0	8420.0	309.0	2390.0	945.0	2130.0	19300.0	40800.9
15.0	8420.0	306.0	2390.0	927.0	2320.0	19200.0	41100.0
20.0	8300.0	309.0	2390.0	944.0	2110.0	19700.0	41000.0
25.0	8320.0	309.0	2530.0	939.0	2150.0	19600.0	41200.0
35.0	8300.0	309.0	2530.0	947.0	2120.0	19300.0	41000.0
40.0	8360.0	310.0	2480.0	939.0	2150.0	19200.0	41100.0
45.0	8380.0	309.0	2530.0	959.0	2260.0	19300.0	41000.0
52.0	8420.0	309.0	2480.0	975.0	2090.0	19200.0	41800.0
66.0	8360.0	309.0	2480.0	975.0	2150.0	19400.0	42300.0
93.0	8360.0	309.0	2530.0	994.0	2130.0	19400.0	41600.0
199.0	8486.0	307.0	2480.0	984.0	2120.0	19400.0	41600.0
279.0	8260.0	306.0	2430.0	994.0	2130.0	19200.0	41500.0
400.0	8180.0	301.0	2480.0	978.0	2130.0	18900.0	40800.0
530.0	7990.0	292.0	2390.0	991.0	2120.0	18800.0	40200.0
697.0	7930.0	287.0	2430.0	978.0	2160.0	18300.0	28400.0
1031.0	7480.0	273.0	2430.0	947.0	2180.0	17500.0	38700.0
1363.0	7110.0	260.0	2340.0	892.0	2180.0	16800.0	37700.0
1601.0	7010.0	253.0	2230.0	892.0	2230.0	16400.0	36000.0
1830.0	6560.0	242.0	2120.0	827.0	2180.0	15400.0	34500.0

FE 36 continued

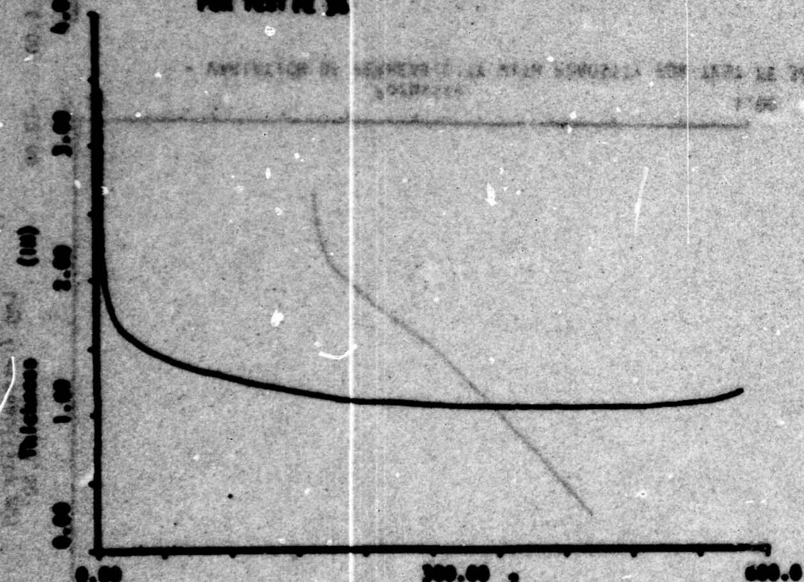
2102.0	6370.0	234.0	2010.0	838.0	2180.0	14900.0	32000.0
2593.0	6110.0	212.0	1960.0	760.0	2130.0	13600.0	31800.0
3067.0	5780.0	200.0	1760.0	705.0	2160.0	12700.0	37700.0
3350.0	5720.0	192.0	1720.0	663.0	2120.0	12200.0	32700.0
3725.0	5510.0	186.0	1610.0	624.0	2320.0	11700.0	27400.0
4176.0	5390.0	173.0	1500.0	569.4	2130.0	11200.0	28900.0
4671.0	5310.0	168.0	1500.0	543.0	2300.0	11000.0	25400.0
4960.0	5510.0	165.0	1560.0	593.0	2370.0	10500.0	27300.0



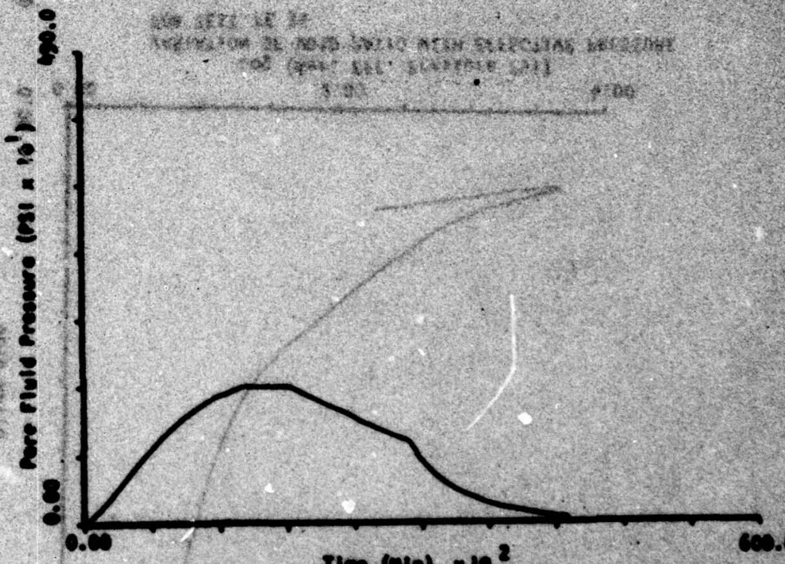
- VARIATION OF EFFECTIVE AXIAL PRESSURE WITH TIME FOR TEST FE 36



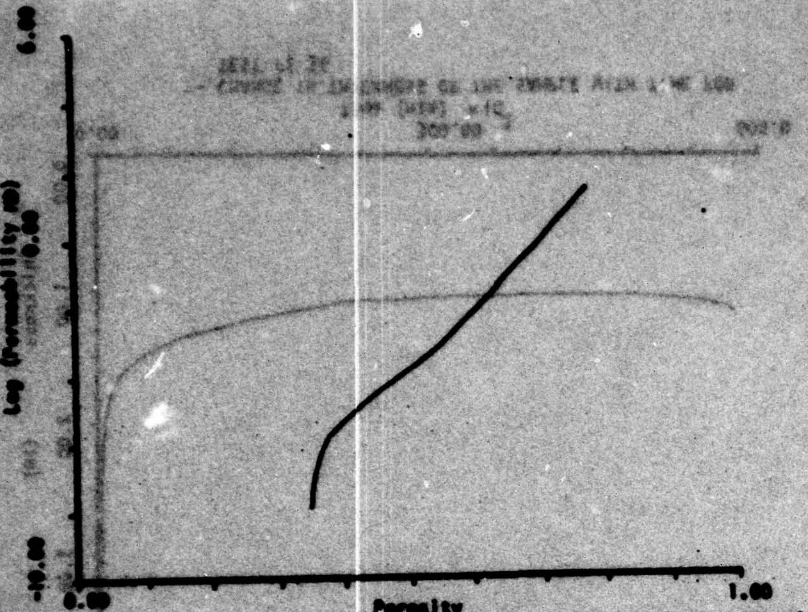
- VARIATION OF AXIAL PRESSURE WITH TIME FOR TEST FE 36



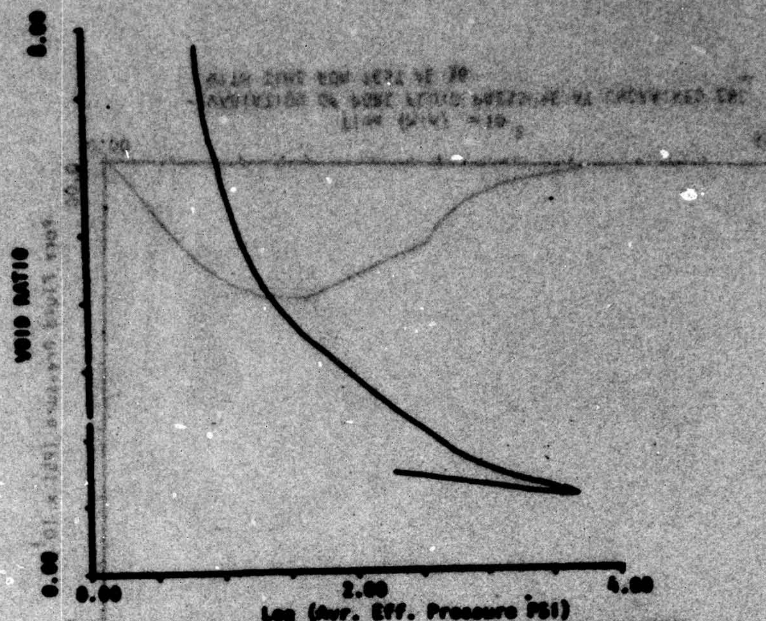
- CHANGE IN THICKNESS OF THE SAMPLE WITH TIME FOR TEST FE 36



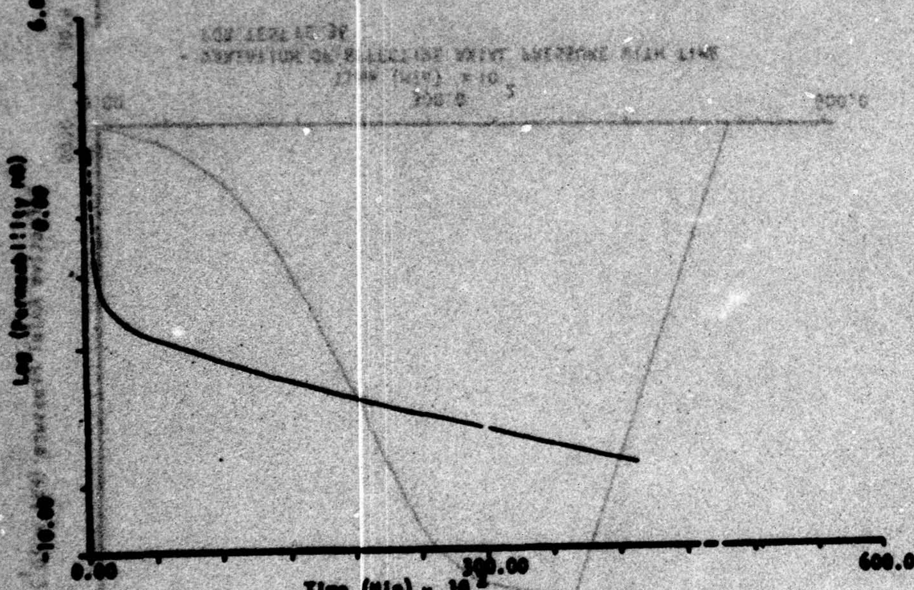
- VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME FOR TEST FE 36



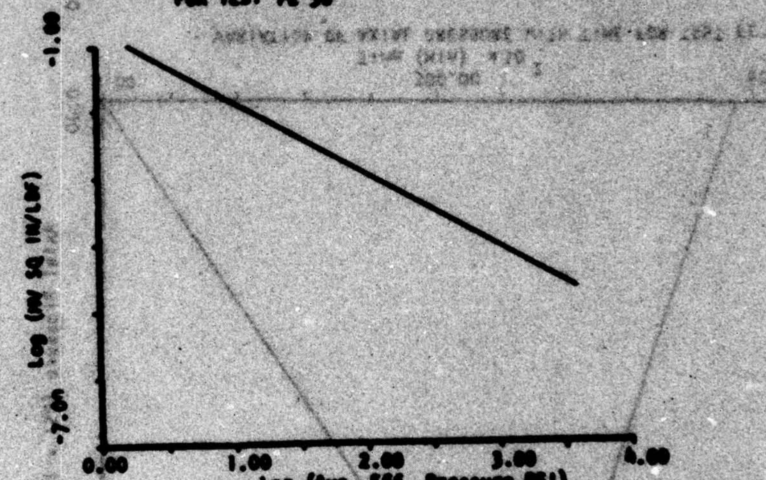
- VARIATION OF PERMEABILITY WITH POROSITY FOR TEST FE 36



VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE FOR TEST FE 36



- VARIATION OF PERMEABILITY WITH TIME FOR TEST FE 36



- VARIATION OF COEFF. OF VOLUME DECREASE WITH EFFECTIVE PRESSURE FOR TEST FE 36

TEST NO. FE 37 Date 21.10.77

DETAILS OF TEST MATERIAL

Fullers Earth remoulded in saline water and allowed to soak for 21 days before sedimenting direct into Cell

TYPE OF TEST

Rate of loading; 10 psi/hr

Rate of unloading; 20 psi/hr

Salinity of initial pore fluid; unit salinity

Maximum consolidation pressure; 8000 psi for 13 days

PROPOSED INVESTIGATION

Compaction of Ca-montmorillonite at a temperature gradient of $10^{o}C/1000$ psi from $20^{o}C$

INITIAL CONDITION OF SAMPLE

Thickness; 3.421 inches

Air dry weight; 356.4 g

FINAL CONDITION OF SAMPLE

Moisture content; 30.3%

Thickness; 1.154 inches

Weight; 426.0 g

FURTHER COMMENTS

Heaters failed when $40^{o}C$ had been attained and test was continued at room temperature.

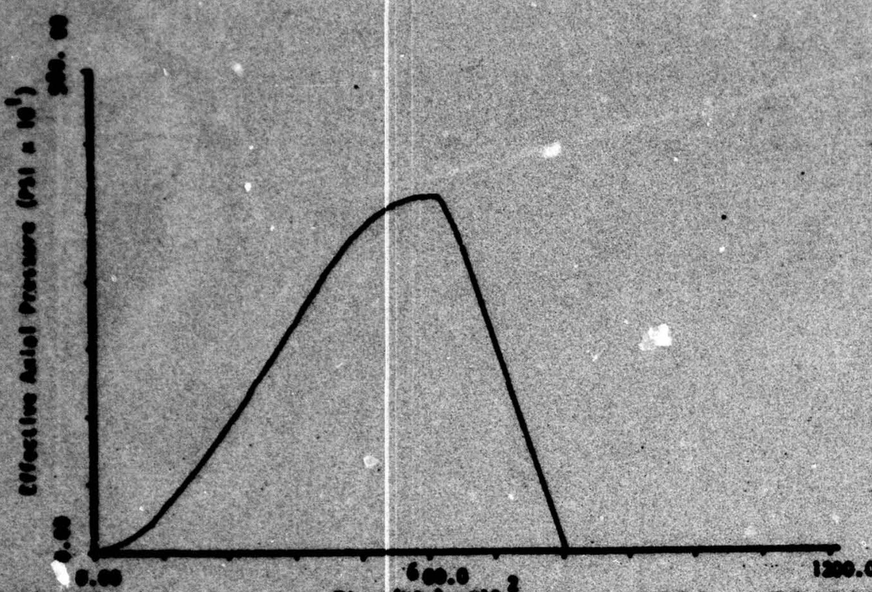
TABLE 10.4 - Results of chemical analysis of pore fluids expelled from FE 37

xial Pressure MN/m^2	Concentration mg/1						
	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	cl^-	t.d.s.
6.0	8300.0	321.0	1870.0	574.0	2220.0	18800.0	38900.9
8.0	8400.0	323.0	1840.0	583.0	2230.0	18500.0	38900.0
10.0	8360.0	320.0	1860.0	583.0	2240.0	18700.0	38600.0
14.0	8520.0	323.0	1840.0	583.0	2270.0	18600.0	38800.0
20.0	8400.0	321.0	1810.0	590.0	2250.0	18700.0	38700.9
20.0	8590.0	321.0	1840.0	510.0	2260.0	19700.0	38500.0
22.0	8460.0	324.0	1840.0	596.0	2260.0	18800.0	38900.0
25.0	8360.0	321.0	1790.0	596.0	2280.0	18800.0	39200.0
27.0	8670.0	323.0	1840.0	605.0	2400.0	18700.0	38700.0
30.0	8590.0	324.0	1820.0	605.0	2240.0	18800.0	39400.0
32.0	8670.0	321.0	1790.0	605.0	2280.0	18900.0	37800.0
37.0	8710.0	321.0	1820.0	612.0	2160.0	18700.0	40200.0
45.0	8650.0	321.0	1810.0	612.0	2170.0	18900.0	41200.0
52.0	8590.0	328.0	1810.0	621.0	2190.0	18800.0	40000.9
65.0	8670.0	324.0	1970.0	621.0	2230.0	18900.0	39700.0
83.0	8570.0	318.0	1890.0	621.0	2260.0	18700.0	37800.0
97.0	8650.0	321.0	1790.0	621.0	2310.0	19000.0	38400.0
185.0	8710.0	320.0	1810.0	621.0	2200.0	19000.0	38200.0
300.0	8710.0	315.0	1780.0	612.0	2200.0	18700.0	36800.0
424.0	8480.0	318.0	1780.0	621.0	2360.0	18500.0	39400.0
562.0	8200.0	309.0	1780.0	621.0	2320.0	18200.0	35000.0
692.0	8240.0	312.0	1760.0	621.0	2310.0	17700.0	36000.9
822.0	8010.0	303.0	1750.0	612.0	2370.0	17700.0	36100.0
951.0	7930.0	296.0	1760.0	621.0	2340.0	17300.0	35900.0
1197.0	7500.0	290.0	1680.0	521.0	2300.0	16800.0	24900.0

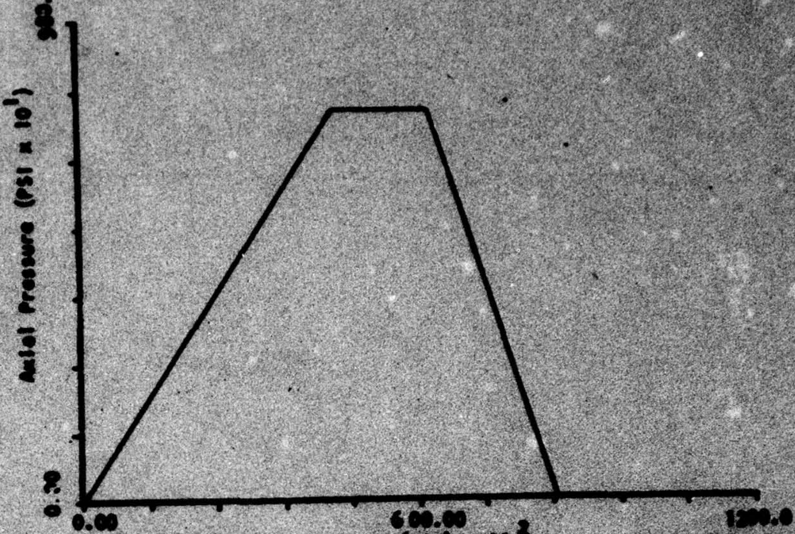
/ continued ...

FE 37 continued

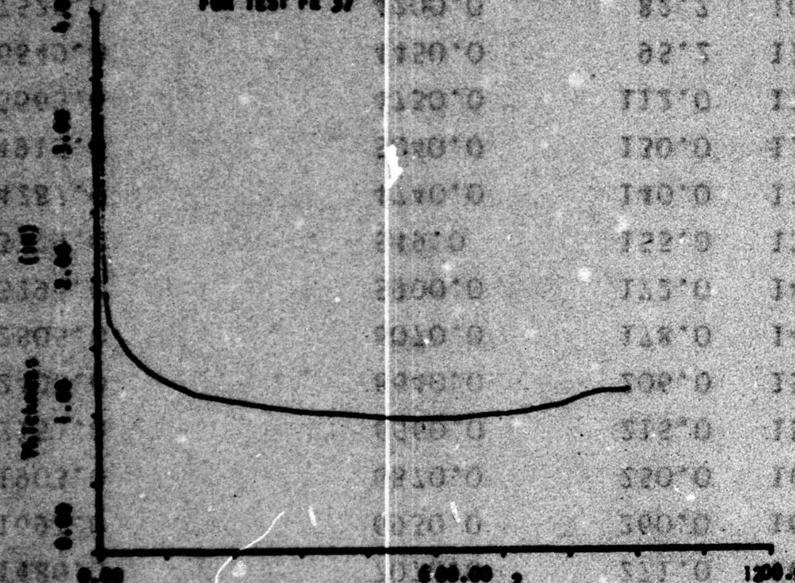
1680.0	7070.0	271.0	1620.0	612.0	2290.0	16000.0	33900.0
1693.0	6930.0	260.0	1620.0	596.0	2240.0	15600.0	35300.0
1903.0	6870.0	250.0	1610.0	596.0	2230.0	15100.0	32800.0
2151.0	6560.0	215.0	1580.0	596.0	2810.0	15200.0	28800.9
2408.0	6640.0	206.0	1580.0	596.0	2180.0	14600.0	24000.0
2805.0	6070.0	178.0	1470.0	583.0	2040.0	13800.0	29200.0
3296.0	5900.0	172.0	1440.0	574.0	1960.0	13200.0	24600.0
3779.0	549.0	153.0	1360.0	562.9	1910.0	12400.0	27100.0
4287.0	4740.0	140.0	1290.0	546.0	1900.0	11600.0	26000.9
4913.0	5040.0	130.0	1220.0	512.0	1840.0	10800.0	24700.0
5665.0	4730.0	112.0	1159.0	496.0	1810.0	10100.0	20800.0
6549.0	4450.0	95.2	1120.0	462.0	1760.0	9350.0	14100.0
7528.0	4200.0	82.7	1030.0	424.0	1730.0	8860.0	13000.9
7997.0	4120.0	74.9	1040.0	42400	1720.0	8570.0	11900.0



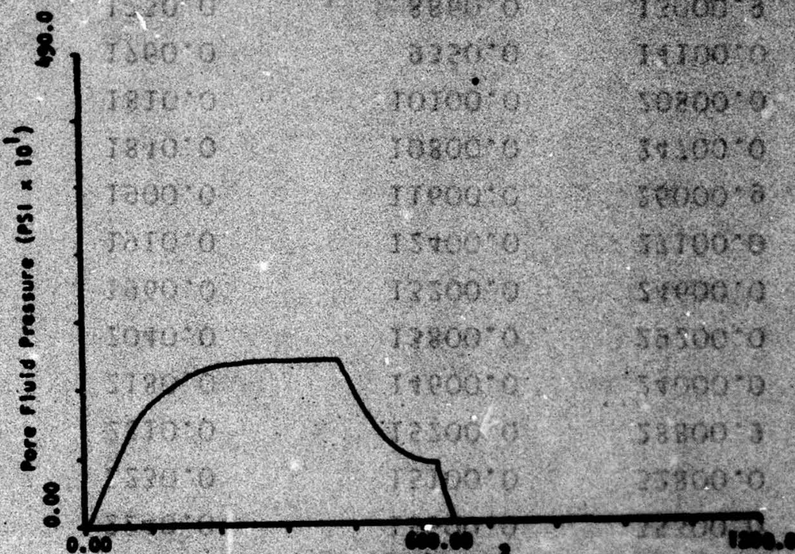
- VARIATION OF EFFECTIVE AXIAL PRESSURE WITH TIME FOR TEST FE 37



- VARIATION OF AXIAL PRESSURE WITH TIME FOR TEST FE 37

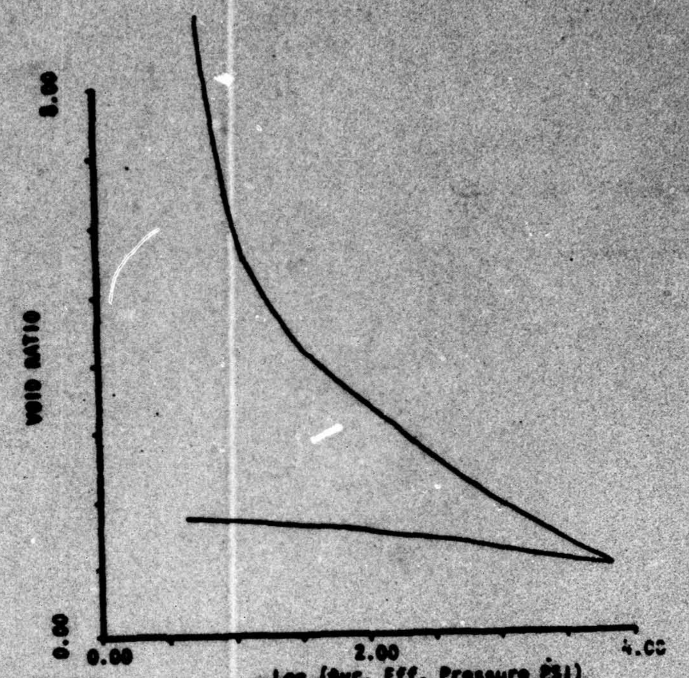


- CHANGE IN THICKNESS OF THE SAMPLE WITH TIME FOR TEST FE 37



- VARIATION OF PORE FLUID PRESSURE AT UNDRAINED END WITH TIME FOR TEST FE 37

FIG. 47 - VARIATION OF PERMEABILITY WITH POROSITY FOR TESTFE 37



VARIATION OF VOID RATIO WITH EFFECTIVE PRESSURE FOR TEST FE 37

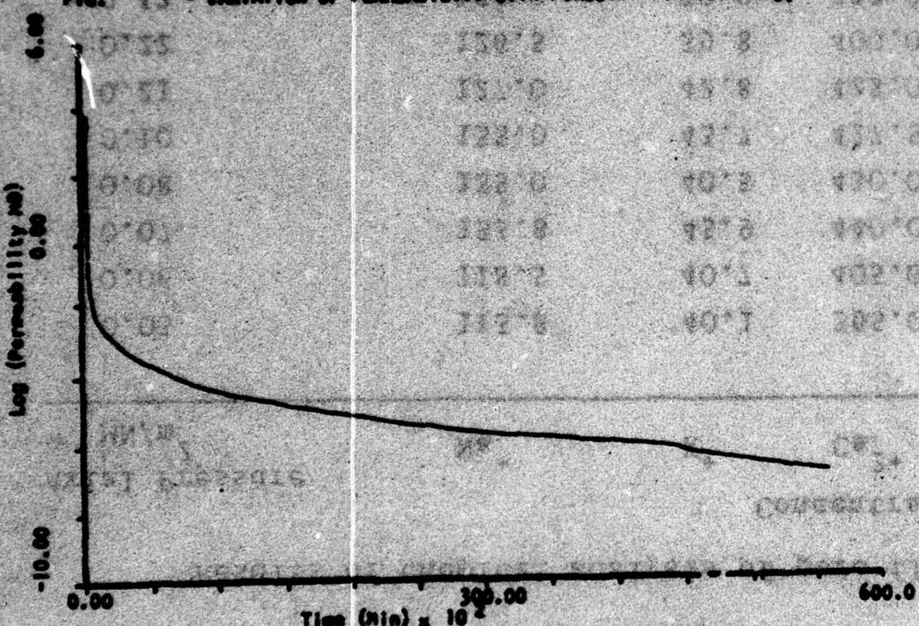
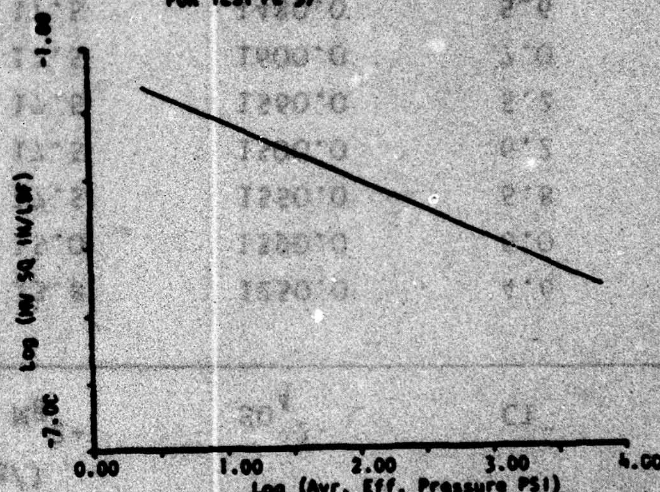


FIG. - VARIATION OF PERMEABILITY WITH TIME FOR TEST FE 37



- VARIATION OF COEFF. OF VOLUME DECREASE WITH EFFECTIVE PRESSURE FOR TEST FE 37

TABLE 10.5

Results of chemical analysis of pore fluids expelled from FE 25

Axial Pressure MN/m^2	Concentration mg/1 Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
0.03	113.8	40.1	365.0	13.8	1250.0	4.6	2250.0
0.06	118.5	40.7	405.0	15.0	1390.0	6.0	2450.0
0.07	133.8	45.9	440.0	17.5	1550.0	5.8	2550.0
0.08	135.0	40.5	430.0	17.5	1500.0	6.2	2500.0
0.10	135.0	43.7	427.5	17.5	1560.0	5.2	2450.0
0.21	127.0	42.8	425.0	17.5	1600.0	7.0	2650.0
0.22	126.5	39.8	400.0	17.5	1480.0	5.6	2850.0
0.42	124.0	36.0	390.0	17.5	1660.0	10.4	2850.0

TEST NO. FE 28 **Date 18.3.76**

DETAILS OF TEST MATERIAL

Fullers Earth remoulded in saline water and placed in Rowe Cell

TYPE OF TEST

Rate of loading; increments of 10 psi

Rate of unloading; 100 psi/hr

Salinity of initial pore fluid; non saline

Maximum consolidation pressure; 30 psi

PROPOSED INVESTIGATION

Compaction of Ca-montmorillonite at 30°C

INITIAL CONDITION OF SAMPLE

Thickness; 57 mm

Moisture content; 120.3%

FINAL CONDITION OF SAMPLE

Thickness; 41 mm

Moisture content; 73.8%

FURTHER COMMENTS

TABLE 10.6 -Results of chemical analysis of pore fluids expelled from FE 28

xial Pressure lb/in^2	Concentration mg/1 Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
3.0	83.0	31.0	242.5	11.3	800.0	4.9	1400.0
6.0	122.0	42.0	460.0	22.5	1450.0	4.9	3050.0
11.5	155.5	57.0	567.5	28.8	1580.0	4.9	3000.0
20.5	153.5	57.5	585.0	28.8	1620.0	4.9	3700.0
29.6	155.5	57.0	575.0	27.5	1620.0	4.9	3000.0
29.5	152.5	54.0	580.0	27.5	1620.0	4.9	3150.0
28.9	134.0	42.3	492.5	25.0	2010.0	4.9	4150.0

TEST NO. FE 31 Date 30.3.76

DETAILS OF TEST MATERIAL

Fullers Earth remoulded in saline water and placed in Rowe Cell

TYPE OF TEST

Rate of loading; increments of 10 psi

Rate of unloading; decrements of 10 psi

Salinity of initial pore fluid; unit salinity

Salinity of substitution fluid; non saline

Maximum consolidation pressure; 90 psi

PROPOSED INVESTIGATION

Compaction of Ca-montmorillonite with substitution of pore fluid at 20°C

INITIAL CONDITION OF SAMPLE

Thickness; 57 mm

Moisture content; 114.1%

FINAL CONDITION OF SAMPLE

Thickness; 39 mm

Moisture content; 66.7%

FURTHER COMMENTS

TABLE 10.7 - Results of chemical analysis of pore fluids expelled from FE 31

Concentration mg/1

Axial Pressure lb/in^2	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2+}	Cl^-	t.d.s.
2.7	8300.0	457.0	2180.0	975.0	2100.0	19400.0	38800.0
5.9	7380.0	409.0	5400.0	780.0	1440.0	22300.0	44200.0
7.0	5080.0	278.0	2740.0	569.0	1560.0	22300.0	44300.9
17.0	6990.0	374.0	5300.0	679.0	1330.0	22100.0	44400.0
18.8	6990.0	382.0	5150.0	741.0	1360.0	22300.0	44500.0
20.3	6990.0	378.0	5230.0	725.0	1370.0	2240.0	44300.0
19.4	7010.0	381.0	5150.0	741.0	1330.0	22300.0	44300.0
20.9	6860.0	374.0	4980.0	741.0	1290.0	22300.0	44500.0
19.2	6620.0	359.0	4820.0	764.0	1330.0	22300.0	64600.0
18.7	6030.0	335.0	4100.0	694.0	1440.0	18800.0	37900.0
36.6	5760.0	320.0	3590.0	710.0	1400.0	16600.0	31350.0
43.5	6000.0	339.0	3810.0	679.0	1470.0	17600.0	35400.0
52.8	5410.0	303.0	3490.0	507.0	1390.0	15500.0	30000.0
52.7	5160.0	292.0	3150.0	523.0	1440.0	14700.0	28450.0
52.7	5060.0	290.0	3070.0	538.0	1470.0	14500.0	28750.0
52.1	5080.0	287.0	3030.0	5380.0	1520.0	14500.0	28150.0
51.5	5160.0	280.0	2900.0	515.0	1480.0	14000.0	26800.0
87.2	5060.0	281.0	2870.0	491.0	1520.0	13400.0	26200.0
86.3	4710.0	267.0	2670.0	476.0	1520.0	12800.0	26050.0
86.3	4530.0	261.0	2430.0	452.0	1540.0	11800.0	23450.0
87.3	4900.0	250.0	2280.0	406.0	1640.0	11500.0	24200.9
88.3	4180.0	242.0	2280.0	382.0	1630.0	11000.0	25000.0

TEST NO. FE 33 Date 12.5.76

DETAILS OF TEST MATERIAL

Fullers Earth remoulded in saline water and placed in Rowe Cell

TYPE OF TEST

Rate of loading; increments of 10 psi

Rate of unloading; decrements of 10 psi

Salinity of initial pore fluid; unit salinity

Salinity of substitution fluid; non saline

Maximum consolidation pressure; 60 psi

PROPOSED INVESTIGATION

Compaction of Ca-montmorillonite with substitution of pore fluid at 40°C

INITIAL CONDITION OF SAMPLE

Thickness; 60 mm

Moisture content; 114.6%

FINAL CONDITION OF SAMPLE

Thickness; 40 mm

Moisture content; 69.4%

FURTHER COMMENTS

TABLE 10.8-Results of chemical analysis of pore fluids expelled from FE 33

Axial Pressure MN/m^2	Concentration mg/1 Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
19.5	8460.0	352.6	2070.0	1130.0	2600.0	21500.0	52050.0
22.2	6800.0	358.8	7030.0	702.0	1640.0	21600.0	46600.0
28.8	6780.0	354.1	7810.0	680.0	1610.0	22000.0	46100.0
32.4	6640.0	351.0	6740.0	702.0	1560.0	21600.0	45900.0
33.0	6740.0	344.8	6740.0	703.0	1520.0	21600.0	45200.0
32.7	6440.0	329.2	6050.0	663.0	1540.0	22200.0	48800.0
33.0	6560.0	3323.3	5370.0	686.0	1530.0	21600.0	45200.0
32.5	6390.0	327.6	6250.0	668.0	1510.0	22000.0	48250.0
55.1	6350.0	327.6	5860.0	679.0	1540.0	21100.0	46450.0
60.4	6030.0	308.9	6250.0	633.0	1580.0	20000.0	42700.0
61.5	5580.0	283.9	5660.0	516.0	1580.0	17800.0	38500.0
61.9	5200.0	265.2	4780.0	445.0	1620.0	1400.0	34550.0
62.4	5000.0	259.0	4780.0	416.0	1660.0	15200.0	32550.0
62.6	4530.0	227.8	3090.0	328.0	1720.0	12900.0	28700.0
62.2	4180.0	207.5	2680.0	280.8	1780.0	11200.0	23850.0
62.5	3750.0	196.6	2230.0	243.0	1810.0	9840.0	22300.0
62.4	3520.0	179.4	1950.0	226.0	2060.0	8570.0	18900.0
62.5	2890.0	148.2	1440.0	167.0	2020.0	6620.0	16150.0
62.9	2790.0	145.1	1310.0	163.8	2840.0	5940.0	15800.0
62.9	1870.0	103.0	858.0	87.4	3050.0	2920.0	10350.0
62.7	1580.0	84.2	733.0	73.3	2920.0	1850.0	8450.0
63.4	1110.0	62.4	546.0	46.8	2710.0	974.0	9100.0
63.3	996.0	56.2	530.0	40.6	2680.0	633.2	6100.0
63.3	918.0	49.9	499.0	40.6	2830.0	535.8	5250.0
63.4	918.0	49.9	546.0	43.7	3000.0	409.2	5400.0
63.3	898.0	49.9	515.0	37.4	3660.0	272.8	3750.0

FE 33 continued

63.1	703.0	43.7	452.0	31.2	2830.0	238.8	5600.0
63.1	742.0	43.7	452.0	35.9	2880.0	175.4	4100.0
63.2	742.0	43.7	452.0	35.9	2830.0	185.4	5100.0
63.5	703.0	42.1	452.0	35.9	2760.0	116.9	4600.0

TEST NO. FE 34 **Date 2.8.76**

DETAILS OF TEST MATERIAL

Fullers Earth remoulded in saline water and placed in Rowe Cell

TYPE OF TEST

Rate of loading; increments of 10 psi

Rate of unloading; 10 psi/hr

Salinity of initial pore fluid; unit salinity

Salinity of substitution fluid; non saline

Maximum consolidation pressure; 85 psi

PROPOSED INVESTIGATION

Compaction of Ca-montmorillonite with substitution of pore fluid at 60°C

INITIAL CONDITION OF SAMPLE

Thickness; 75mm

Moisture content; 126.9%

FINAL CONDITION OF SAMPLE

Thickness; 40 mm

Moisture content; 56.6%

FURTHER COMMENTS

TABLE 10.9 - Results of chemical analysis of pore fluids expelled from FE 34

Axial Pressure lb/in^2	Concentration mg/l Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
5.8	5937.0	243.0	3058.0	521.0	1700.0	25300.0	44900.9
5.8	7109.0	332.0	3416.0	555.0	1710.0	21000.0	44600.0
5.8	6640.0	340.0	3370.0	558.0	1610.0	21100.0	45800.0
11.0	6992.0	268.0	2699.0	443.0	1480.0	20600.0	42900.0
19.5	6836.0	340.0	3120.0	5930.0	1500.0	20300.0	42200.0
19.4	7011.0	343.0	3370.0	668.0	1640.0	21000.0	44300.0
30.0	6230.0	303.0	3167.0	596.0	1520.0	20300.0	42600.0
38.0	6757.0	321.0	3120.0	627.0	1400.0	20600.0	42900.0
80.0	6679.0	318.0	3323.0	633.0	1480.0	20900.0	43500.0
80.0	6640.0	315.0	3416.0	608.0	1440.0	21000.0	43800.0
80.0	6562.0	318.0	3323.0	622.0	1440.0	20800.0	43700.0
80.0	1348.0	74.9	452.0	53.0	860.0	2820.0	6800.0
80.0	1758.0	95.2	359.0	71.8	890.0	3700.0	8750.0
80.0	1543.0	87.4	967.0	90.5	650.0	4190.0	9600.0
80.0	801.0	42.1	359.0	37.4	420.0	2140.0	5150.0
80.0	5468.0	226.0	3214.0	458.0	1150.0	17600.0	37800.0
80.0	5410.0	256.0	3323.0	406.0	1040.0	16500.0	34600.0
80.0	5468.0	256.0	3167.0	384.0	1170.0	15900.0	33900.0
80.0	5566.0	262.0	3167.0	395.0	1160.0	16800.0	31500.0
80.0	5312.0	254.0	3058.0	362.0	1150.0	15600.0	32800.0
80.0	4765.0	228.0	2668.0	323.0	1040.0	13500.0	10800.0
83.5	4140.0	201.0	2231.0	245.0	1130.0	11100.0	10600.0
83.5	3633.0	181.0	1919.0	195.0	1180.0	9550.0	20700.0

/ continued ...

FE 34 continued

84.5	3105.0	153.0	1388.0	128.0	1160.0	7500.0	17800.0
84.5	2793.0	140.0	1295.0	10.30	1210.0	7010.0	17200.0
84.5	2129.0	101.0	874.0	71.8	1210.0	5260.0	12900.0
84.5	2246.0	112.0	562.0	53.0	1490.0	5460.0	13900.0
84.5	1250.0	64.0	359.0	40.6	1260.0	2830.0	7700.0
86.0	1016.0	51.5	359.0	29.6	1200.0	2150.0	6450.0
86.0	1016.0	51.5	312.0	28.1	1300.0	1860.0	6150.0
86.0	996.0	48.4	312.0	31.2	1400.0	1760.0	5800.0
86.0	781.0	34.3	265.0	38.1	1400.0	1170.0	4150.0
86.0	644.0	28.1	172.0	15.6	1280.0	977.0	3650.0
86.0	859.0	40.6	312.0	23.4	1490.0	1070.0	4100.0
86.0	898.0	45.2	359.0	21.8	1750.0	879.0	4500.0
86.0	1133.0	45.2	312.0	25.0	1840.0	879.0	5000.0

TEST NO. FE 38

Date 6.8.76

DETAILS OF TEST MATERIAL

Fullers Earth remoulded in saline water and allowed to soak for 3 days before sedimenting direct into Cell

TYPE OF TEST

Rate of loading; 10 ppi/hr

Rate of unloading; 20 psi/hr

Salinity of initial pore fluid; unit salinity

Maximum consolidation pressure; 5000 psi for 9 days

PROPOSED INVESTIGATION

Compaction of Ca-montmorillonite at a temperature gradient of $10^{o}C/1000$ psi from $20^{o}C$

INITIAL CONDITION OF SAMPLE

Thickness; 3.103 inches

Air dry weight; 401.1 g

FINAL CONDITION OF SAMPLE

Moisture content; 27.8%

Thickness; 1.195inches

Weight; 442.3 g

FURTHER COMMENTS

Unloaded at room temperature

TABLE 10.10 - Results of chemical analysis of pore fluids expelled from FE 38

Concentration mg/1

Axial Pressure lb/in^2	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	t.d.s.
9.5	165.0	31.2	421.0	21.8	1580.0	5.0	4150.0
9.5	165.0	40.6	421.0	20.3	1700.0	5.0	4850.0
14.7	156.0	34.3	460.0	20.3	1750.0	5.0	3000.0
19.3	159.0	34.3	476.0	18.7	1700.0	5.0	3300.0
19.3	153.0	31.2	499.0	20.3	1680.0	5.0	2950.0
20.5	128.0	25.0	421.0	18.7	1680.0	5.0	1700.0
42.6	158.0	31.2	476.2	18.7	1640.0	5.0	1300.0
42.6	156.0	28.1	499.0	20.3	1660.0	5.0	2800.0
42.6	165.0	31.2	515.0	20.3	1610.0	5.0	2850.0
83.0	165.0	36.2	460.0	18.7	1610.0	5.0	2400.0
83.0	158.0	29.6	515.0	18.7	1590.0	5.0	3000.0
83.0	158.0	28.1	515.0	18.7	1600.0	5.0	2800.0
83.0	172.0	31.2	499.0	18.7	1580.0	5.0	2900.0
84.0	175.0	13.2	499.0	17.2	1540.0	45.0	2900.0
84.0	165.0	25.0	530.0	17.2	1500.0	97.4	2600.0
84.0	173.0	25.0	562.0	17.2	1440.0	195.0	3050.0
85.0	208.0	32.8	772.0	20.3	1280.0	682.0	3750.0
85.0	287.0	46.8	1060.0	25.0	1190.0	1560.0	5550.0
85.0	752.0	92.0	1960.0	59.3	1060.0	4290.0	12000.0
85.0	805.0	84.2	1810.0	53.0	1030.0	3900.0	10600.0
85.0	805.0	76.4	1820.0	49.9	1020.0	3900.0	11200.0
85.0	842.0	84.2	1950.0	53.0	1000.0	4190.0	11900.0
85.0	898.0	93.6	2110.0	65.5	980.0	5160.0	13200.0
85.0	1170.0	112.3	2530.0	90.5	960.0	6820.0	19300.0
85.0	1720.0	142.0	2740.0	118.6	910.0	8860.0	25500.0
87.7	2210.0	160.7	2890.0	131.0	900.0	9940.0	25700.0

TABLE 10.11

Results of small shear box tests on specimens compacted in the high pressure oedometer.

	Peak values		Residual values	
	C' kN/m^2	ø'	C' kN/m^2	ø'
FE 16	850	55	40	35
FE 24	575	69	30	30
FE 27	350	49	90	28
FE 29	460	49	60	30
FE 30	860	58	0	32
FE 32	320	60	10	36
FE 35	370	40	60	17
FE 36	470	57	15	33
FE 37	450	55	0	36

APPENDIX 1

UNITS

The United Kingdom and member countries of the Europen Economic Community now use, in part, the Systeme International d'Unites (abbreviated to SI). The relationship between SI Units and others in common use is as follows:-

This unit = these units ...

Quantity	UK Imperial	USA units	c.g.s.	SI+
Length	foot	foot	30.48 cm	0.3048 m
	inch	inch	2.54 cm	2.54×10^{-2}m
Area	foot^2	foot^2	929.0 cm^2	0.0929 m^2
	inch^2	inch^2	6.452 cm^2	6.452×10^{-4} m^2
Volume	foot^3	foot^3	28316.8 cm^3	0.0283 m^3
	inch^3	inch^3	16.39 cm^3	16.39×10^{-6}m^2
	UK gal	1.2009 US gal	4.546 l	4.546×10^{-3}m^3
Mass	lb (mass)	0.03108 slugs	453.6 gm-mass	0.4536 kg
Force	lb (force)*	lb wt	453.6 gm-wt	4.448 N
Pressure	lbf in^{-2}	lb wt in^{-2}	70.31 gm cm^{-2}	6.895 kN m^{-2}
Density	lb ft^{-3}	lb ft^{-3}	0.016 gm cm^{-3}	16.018 kg m^{-3}
E	lbf ft^{-2}	lb wt ft^{-2}	0.488 gm cm^{-2}	47.88 Nm^{-2}
m_r	ft^2 ton f^{-1}	ft^2 ton wt^{-1}	0.914 cm^2 kg^{-1}	9.324 m^2 MN^{-1}
c_r	ft^2 year^{-1}	ft^2 year^{-1}	929 cm^2 year^{-1}	0.0929 m^2 year^{-1}
Permeability	ft year^{-1}	ft year^{-1}	30.48 cm year^{-1}	0.3048 m year^{-1}

(+) Basic units of SI are the metre, kilogramme, second and Kelvin, however the year is a commonly used unit of time. 1 year = 31.54×10^6 seconds.

(*) also known in the UK as lb wt or poundal

NEWTON: This is the SI unit of force = mass x g, which by definition in SI units is the force to give a mass of 1 kg an acceleration of 1 m per sec per sec. g = 9.81 m/sec

Commonly used multiples and sub-multiples of units...

M = mega = 10^6

k = kilo = 10^3

m = milli = 10^{-3}

μ = micro = 10^{-6}